Lecture # 13 onwards
Temperature Sensors

Why Temperature Measurement?

- Temperature can have a significant effect on materials and processes at the molecular level
- It is the most widely sensed of all variables

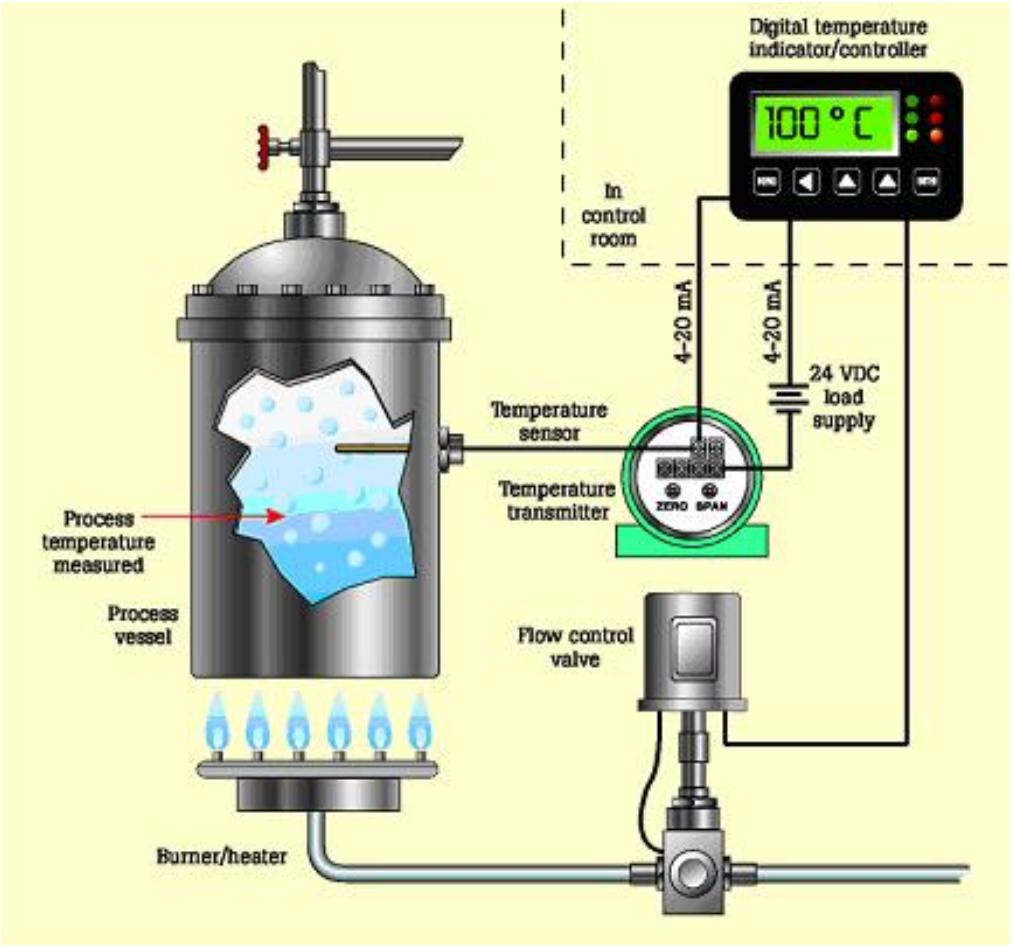
- Temperature is defined as a specific degree of hotness or coldness as referenced to a specific scale.
- It can also be defined as the amount of heat energy in an object or system

Principles of Temperature Measurement

1. Expansion of a material to give visual indication, pressure, or dimensional change
2. Electrical resistance change
3. Semiconductor characteristic change
4. Voltage generated by dissimilar metals
5. Radiated energy

Types of Temperature Sensors

- Thermocouples
- Resistance Temperature Detectors (RTDs)
- Thermistors
- Infrared Sensors
- Semiconductors



Temperature Sensors

- Temperature sensors detect a change in a physical parameter such as resistance or output voltage that corresponds to a temperature change
- There are two basic types of temperature sensing

Contact & Non-Contact Temperature Sensors

- **Contact temperature sensing requires the sensor to be in direct physical** contact with the media or object being sensed.
- It can be used to monitor the temperature of solids, liquids or gases over an extremely wide temperature range.
- **Non-contact measurement interprets the radiant energy of a heat source in the** form of energy emitted in the infrared portion of the electromagnetic spectrum.
- This method can be used to monitor non-reflective solids and liquids but is not effective with gases due to their natural transparency.

Expansion of a material to give visual indication, pressure, or dimensional change

Thermometers

- The operating range of the mercury thermometer is from −30 to 800°F (−35 to 450°C)
- freezing point of mercury −38°F [−38°C]

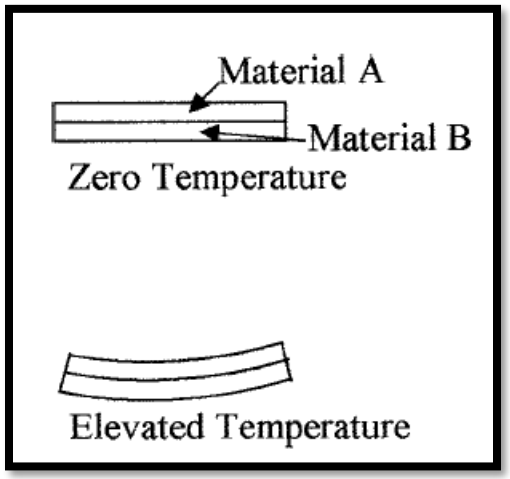
- The toxicity of mercury, ease of breakage, the introduction of cost effective, accurate, and easily read digital thermometers has brought about the demise of the mercury thermometer.

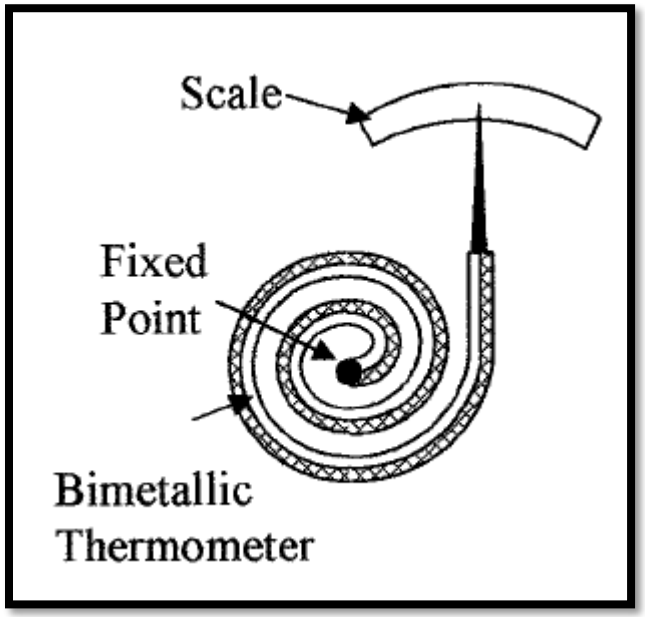
- Liquid in Glass Thermometers with a range of −300 to 600°F (−170 to 330°C).

Expansion of a material to give visual indication, pressure, or dimensional change

Bimetallic Strips

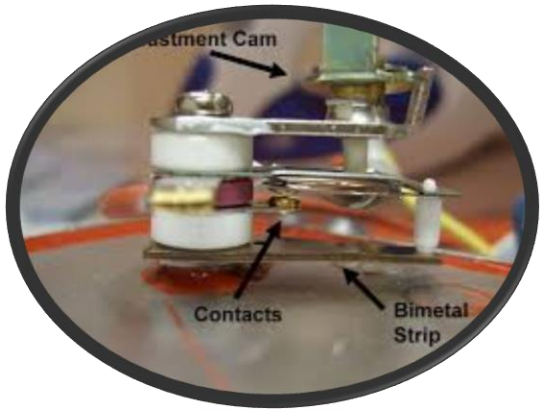
- Bimetallic strip is a type of temperature measuring device that is relatively inaccurate, slow to respond, not normally used in analog applications to give remote indication, and has hystersis.
- ON/OFF applications not requiring high accuracy
- it is rugged and cost effective

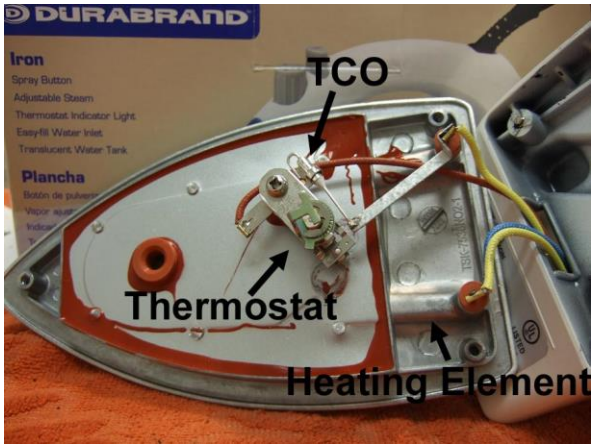




Sensor Types and Technologies

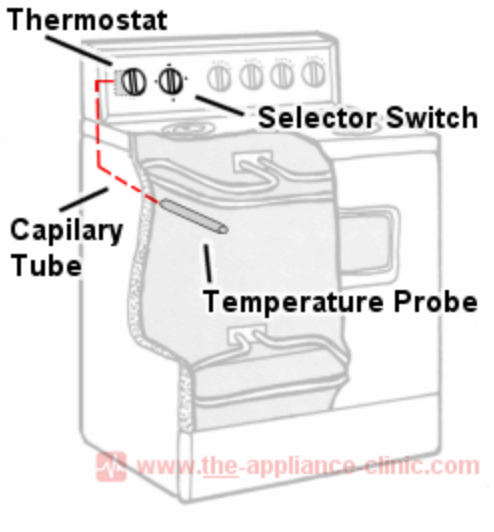
- **Electro-mechanical**
  - **Bi-metal thermostats: two different metals bonded** together under heat and pressure to form a single strip of material.
  - By employing the different expansion rates of the two materials, thermal energy can be converted into electro-mechanical motion.





Sensor Types and Technologies

- **Electro-mechanical**
  - **Bulb and capillary thermostats make use of the capillary action of expanding or** contracting fluid to make or break a set of electrical contacts



Sensor Types and Technologies

- **Electronic**
  - **Silicon sensors make use of the bulk electrical resistance properties of semiconductor** materials, rather than the junction of two differently doped areas
  - IC-type devices can provide a direct, digital temperature reading

Sensor Types and Technologies

- **Electronic**
  - **Infrared (IR) pyrometry. All objects emit infrared energy provided their temperature** is above absolute zero (0 Kelvin).
  - There is a direct correlation between the infrared energy an object emits and its temperature
  - IR sensors measure the infrared energy emitted from an object in the 4–20 micron wavelength and convert the reading to a voltage.
  - Typical IR technology uses a lens to concentrate radiated energy onto a thermopile. The resulting voltage output is amplified
  - and conditioned to provide a temperature reading

Sensor Types and Technologies

- **Electronic**
  - **Thermocouples** are formed when two electrical conductors of dissimilar metals or alloys are joined at one end of a circuit
  - Thermocouples do not have sensing elements so they are less limited than resistive temperature devices (RTDs)

Thermocouple Principle (Seeback Effect)

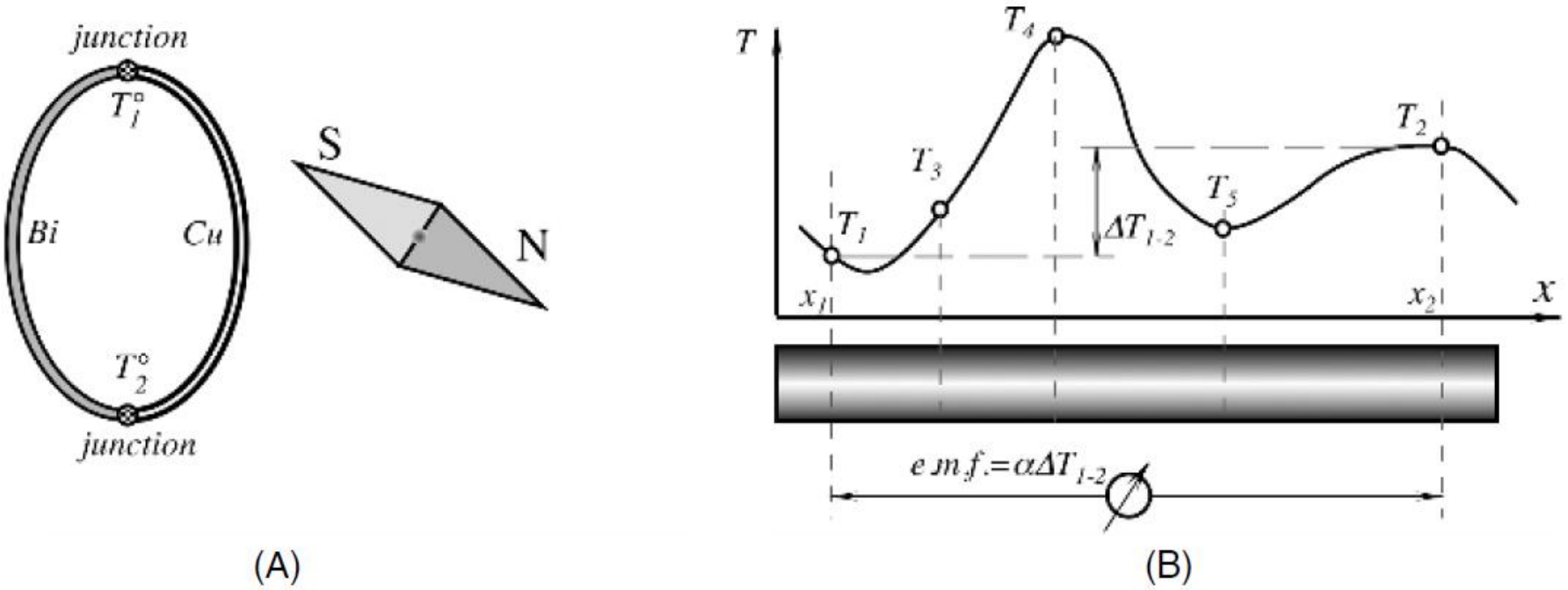


Fig. 3.34. (A) Seebeck experiment; (B) the varying temperature along a conductor is a source of a thermoelectric e.m.f.

Thermocouple Principle (Seeback Effect)

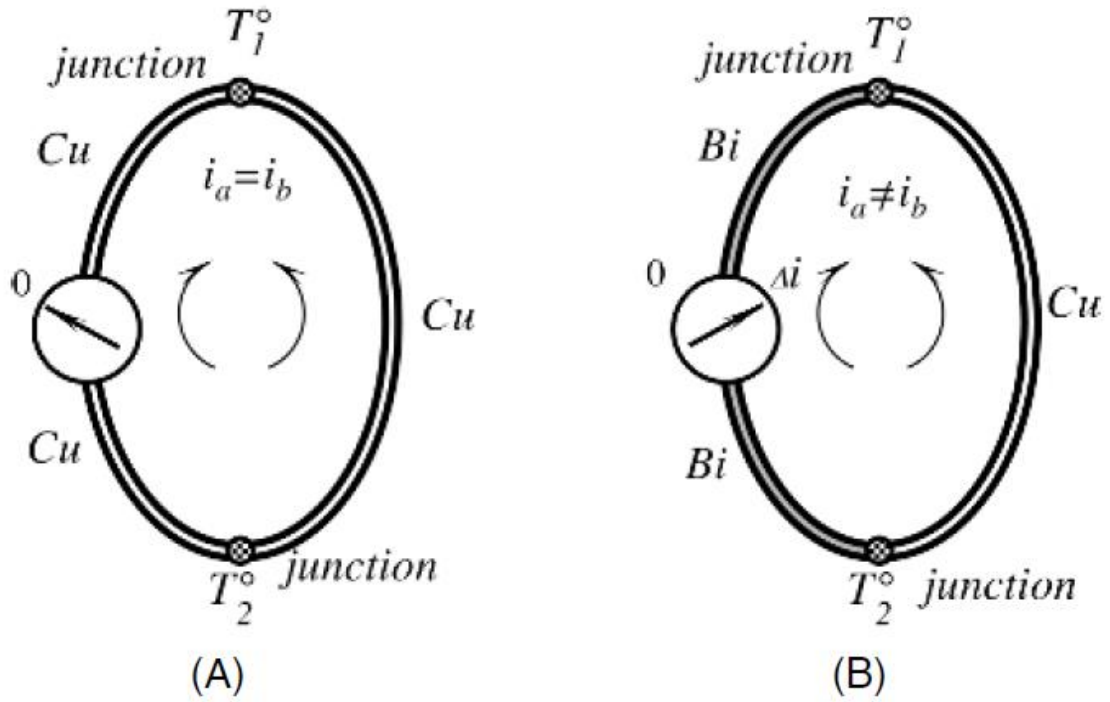


Fig. 3.35. Thermoelectric loop: (A) joints of identical metals produce zero net current at any temperature difference; (B) joints of dissimilar metals produce net current Δi.

Thermocouple Principle

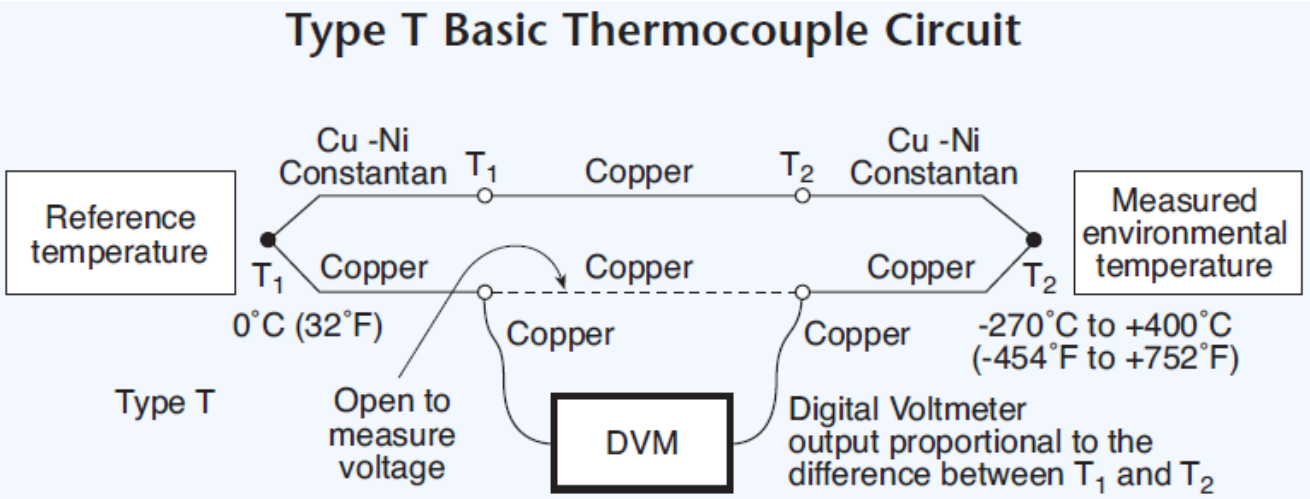
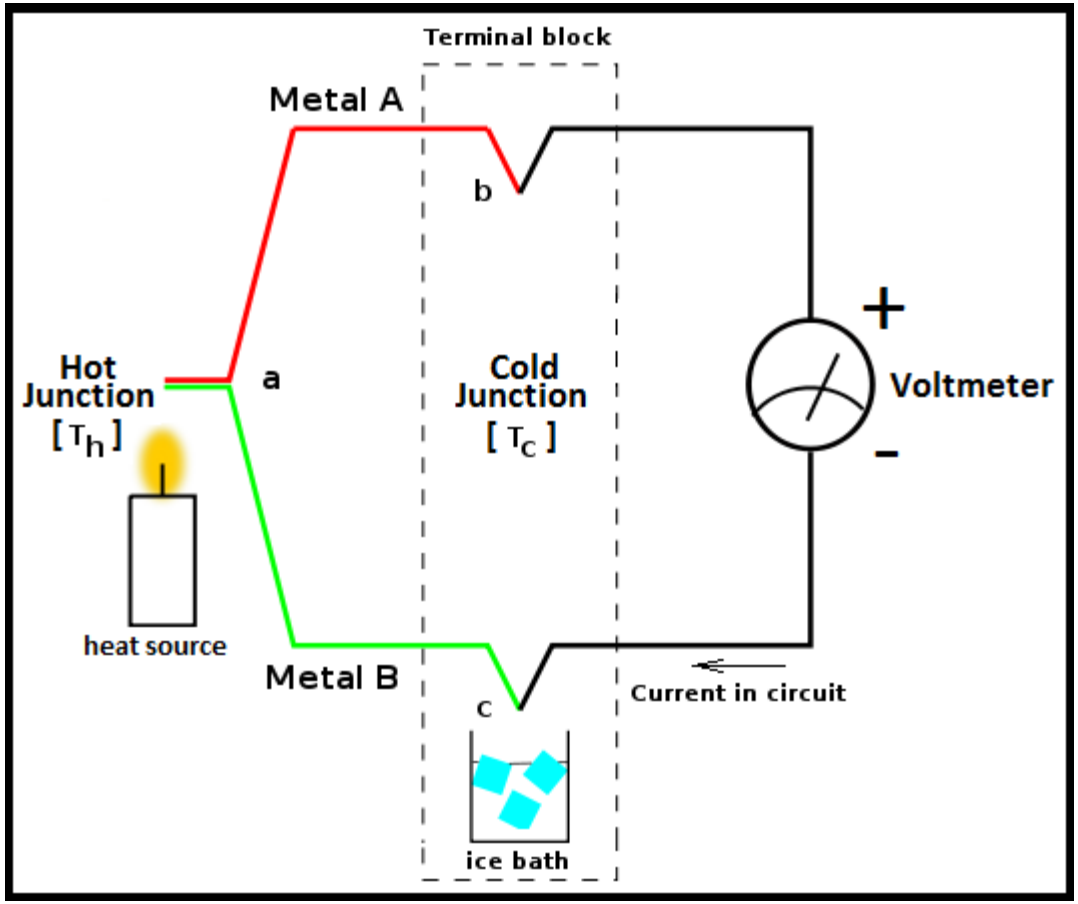


Fig. 6.01. A basic thermocouple measurement system requires two sensors, one for the environment under measurement and the other, a reference junction, normally held to 0˚C (32˚F). Type-T is one of the dozen or more common thermocouples frequently used in general-purpose temperature measuring applications. It is made of copper and constantan metals and typically operates from –270 to +400˚C or –454 to +752˚F.

Basic Thermocouple Circuit



From Seebeck effect, the voltage gradient at any point in the circuit,

$$\nabla V = \mathbf{E}_{\text{emf}} = -S\nabla T$$

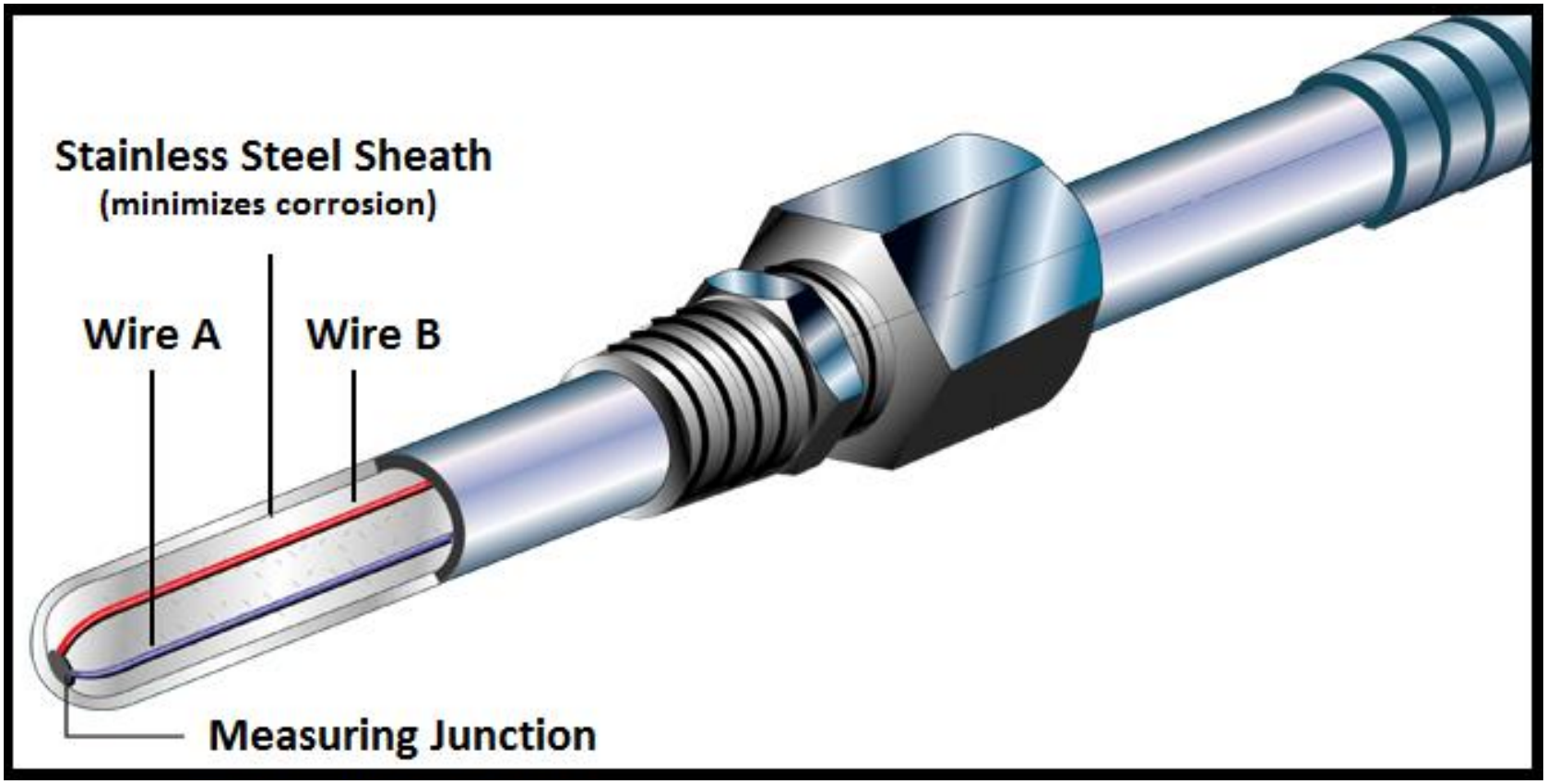
Total measured end-to-end voltage between the junctions,

$$V_{\text{b}} - V_{\text{c}} = \int_{T_{\text{c}}}^{T_{\text{h}}} \left(S_{\text{A}}(T) - S_{\text{B}}(T)\right)\, dT$$

If the S_A and S_B are constant for the given temperature range, then

$$V_b - V_c = (S_A - S_B)(T_h - T_c)$$
$$= S_{AB}(T_h - T_c)$$

How it looks like ?



Its construction consists of two conductors, welded together at the measuring point and insulated from each other along the length, inside an outer protection sheath.

Types of Thermocouples

There are many thermocouples, but only 8 of them are standardized internationally.

BASE METAL

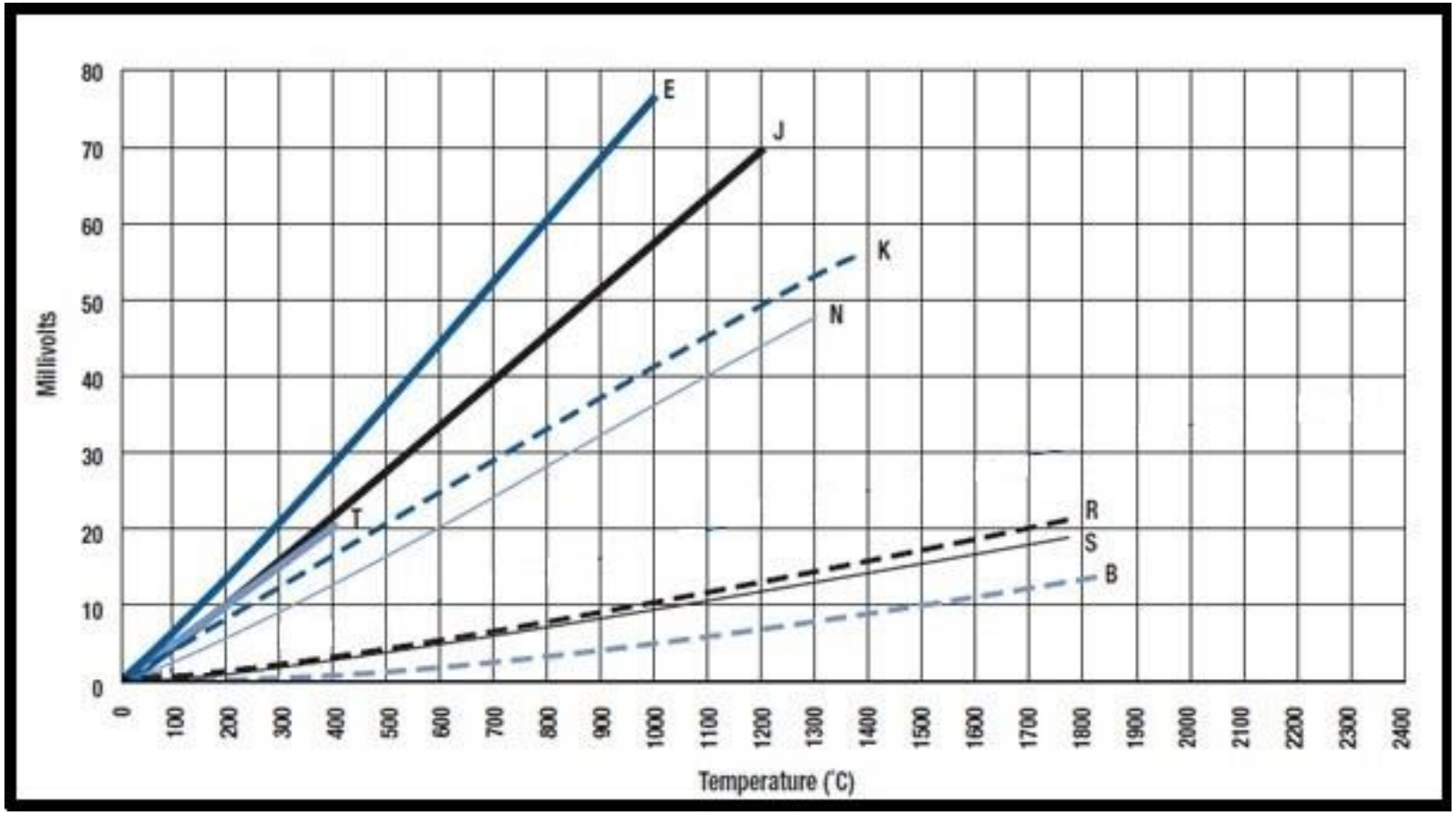
- Type K : Chromel-Alumel
- Type J : Iron-Constantan
- Type E : Chromel-Constantan
- Type N : Nicros-Nisil
- Type T : Copper-Constantan

NOBLE METAL

- Type S : Platinum-Rhodium
- Type R : Platinum-Rhodium
- Type B : Platinum-Rhodium

Each thermocouple type has a specific range of temperature and environment.

Thermocouple EMF vs Temperature



This shows that the various thermocouples differ in their respective sensitivities.

Applications

- Temperature Measurement
- Power Generation
- Radiation Sensors
- Gas Safety Equipments
- Manufacturing Industry

Advantages

- Rugged
- Inexpensive
- Quick response time
- Very simple in construction
- Used to measure temperature ranges spanning thousands of degrees, around -200 C to 2200 C

Disadvantages

- Low accuracy
- Vulnerable to corrosion
- Thermocouple operation is relatively complex with potential sources of error

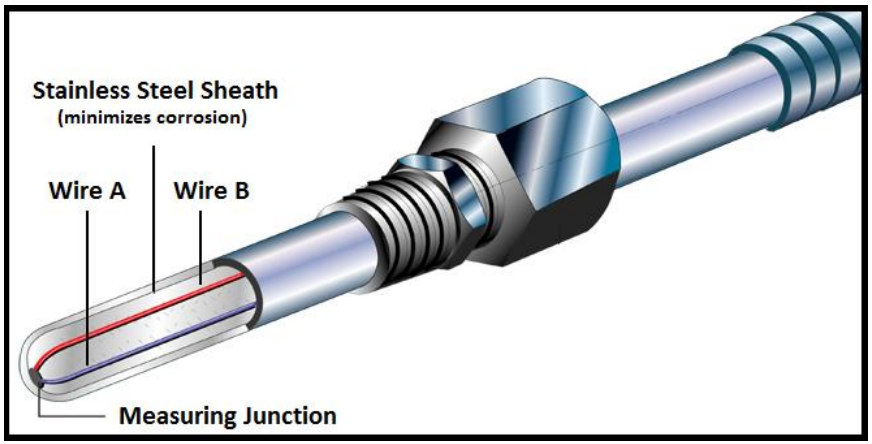
Common Thermocouple Types

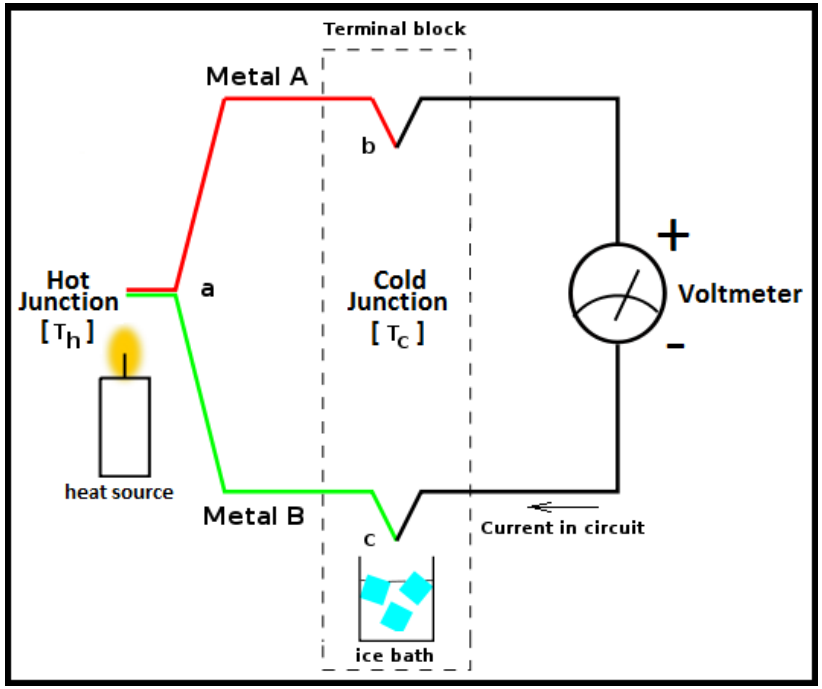
Common Thermocouple Types								
Type	Metal +	Metal −	Standard color code +	Standard color code −	Ω/double foot 20 AWG	Seebeck coefficient S(μV/˚C) @ T(˚C)	˚C standard wire error	NBS specified materials range* (˚C)
B	Platinum-6% Rhodium	Platinum-30% Rhodium	–		0.2	6 600	4.4 to 8.6	0 to 1820**
E	Nickel-10% Chromium	Constantan	Violet	Red	0.71	58.5 0	1.7 to 4.4	-270 to 1000
J	Iron	Constantan	White	Red	0.36	50.2 0	1.1 to 2.9	-210 to 760
K	Nickel-10% Chromium	Nickel	Yellow	Red	0.59	39.4 0	1.1 to 2.9	-270 to 1372
N (AWG 14)	Nicrosil	Nisil	–		–	39 600	–	0 to 1300
N (AWG 28)	Nicrosil	Nisil	–		–	26.2 0	–	-270 to 400
R	Platinum-13% Rhodium	Platinum	–		0.19	11.5 600	1.4 to 3.8	-50 to 1768
S	Platinum-10% Rhodium	Platinum	–		0.19	10.3 600	1.4 to 3.8	-50 to 1768
T	Copper	Constantan	Blue	Red	0.30	38 0	0.8 to 2.9	-270 to 400
W-Re	Tungsten-5% Rhenium	Tungsten-26% Rhenium	–		–	19.5 600	–	0 to 2320

Thermocouples Properties

- Two wires of different metal alloys
- Converts thermal energy into electrical energy
- Requires a temperature difference between measuring junction and reference junction

$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$



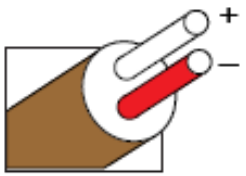


Example Problems

Revised Thermocouple Reference Tables

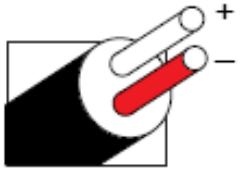
TYPE J

Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90



Thermocouple Grade

Iron vs. Copper-Nickel



Extension Grade

MAXIMUM TEMPERATURE RANGE

Thermocouple Grade
32 to 1382°F
0 to 750°C

Extension Grade
32 to 392°F
0 to 200°C

LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75%
Special: 1.1°C or 0.4%

COMMENTS, BARE WIRE ENVIRONMENT:
Reducing, Vacuum, Inert; Limited Use in Oxidizing at High Temperatures;
Not Recommended for Low Temperatures

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

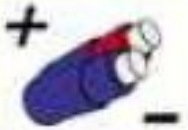
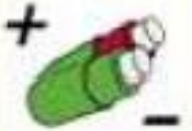
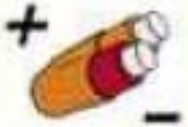
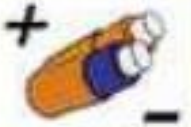
Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-200	-8.095	-8.076	-8.057	-8.037	-8.017	-7.996	-7.976	-7.955	-7.934	-7.912	-7.890	-200
-190	-7.890	-7.868	-7.846	-7.824	-7.801	-7.778	-7.755	-7.731	-7.707	-7.683	-7.659	-190
-180	-7.659	-7.634	-7.610	-7.585	-7.559	-7.534	-7.508	-7.482	-7.456	-7.429	-7.403	-180
-170	-7.403	-7.376	-7.348	-7.321	-7.293	-7.265	-7.237	-7.209	-7.181	-7.152	-7.123	-170
-160	-7.123	-7.094	-7.064	-7.035	-7.005	-6.975	-6.944	-6.914	-6.883	-6.853	-6.821	-160
-150	-6.821	-6.790	-6.759	-6.727	-6.695	-6.663	-6.631	-6.598	-6.566	-6.533	-6.500	-150
-140	-6.500	-6.467	-6.433	-6.400	-6.366	-6.332	-6.298	-6.263	-6.229	-6.194	-6.159	-140
-130	-6.159	-6.124	-6.089	-6.054	-6.018	-5.982	-5.946	-5.910	-5.874	-5.838	-5.801	-130
-120	-5.801	-5.764	-5.727	-5.690	-5.653	-5.616	-5.578	-5.541	-5.503	-5.465	-5.426	-120
-110	-5.426	-5.388	-5.350	-5.311	-5.272	-5.233	-5.194	-5.155	-5.116	-5.076	-5.037	-110
-100	-5.037	-4.997	-4.957	-4.917	-4.877	-4.836	-4.796	-4.755	-4.714	-4.674	-4.633	-100
-90	-4.633	-4.591	-4.550	-4.509	-4.467	-4.425	-4.384	-4.342	-4.300	-4.257	-4.215	-90
-80	-4.215	-4.173	-4.130	-4.088	-4.045	-4.002	-3.959	-3.916	-3.872	-3.829	-3.786	-80
-70	-3.786	-3.742	-3.698	-3.654	-3.610	-3.566	-3.522	-3.478	-3.434	-3.389	-3.344	-70
-60	-3.344	-3.300	-3.255	-3.210	-3.165	-3.120	-3.075	-3.029	-2.984	-2.938	-2.893	-60
-50	-2.893	-2.847	-2.801	-2.755	-2.709	-2.663	-2.617	-2.571	-2.524	-2.478	-2.431	-50
-40	-2.431	-2.385	-2.338	-2.291	-2.244	-2.197	-2.150	-2.103	-2.055	-2.008	-1.961	-40
-30	-1.961	-1.913	-1.865	-1.818	-1.770	-1.722	-1.674	-1.626	-1.578	-1.530	-1.482	-30
-20	-1.482	-1.433	-1.385	-1.336	-1.288	-1.239	-1.190	-1.142	-1.093	-1.044	-0.995	-20
-10	-0.995	-0.946	-0.896	-0.847	-0.798	-0.749	-0.699	-0.650	-0.600	-0.550	-0.501	-10
0	-0.501	-0.451	-0.401	-0.351	-0.301	-0.251	-0.201	-0.151	-0.101	-0.050	0.000	0

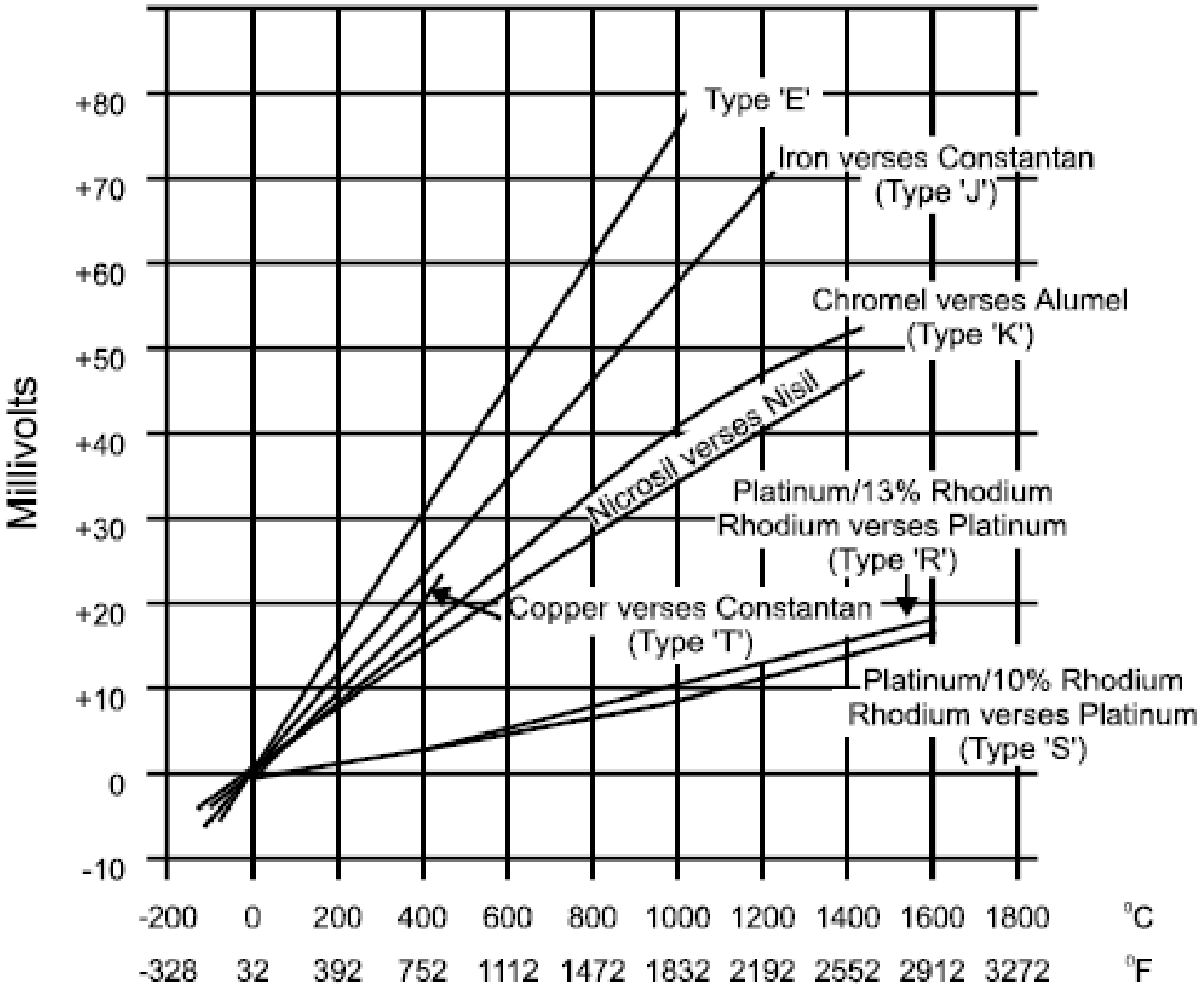
°C	0	1	2	3	4	5	6	7	8	9	10	°C
500	27.393	27.449	27.505	27.561	27.617	27.673	27.729	27.785	27.841	27.897	27.953	500
510	27.953	28.010	28.066	28.122	28.178	28.234	28.291	28.347	28.403	28.460	28.516	510
520	28.516	28.572	28.629	28.685	28.741	28.798	28.854	28.911	28.967	29.024	29.080	520
530	29.080	29.137	29.194	29.250	29.307	29.363	29.420	29.477	29.534	29.590	29.647	530
540	29.647	29.704	29.761	29.818	29.874	29.931	29.988	30.045	30.102	30.159	30.216	540
550	30.216	30.273	30.330	30.387	30.444	30.502	30.559	30.616	30.673	30.730	30.788	550
560	30.788	30.845	30.902	30.960	31.017	31.074	31.132	31.189	31.247	31.304	31.362	560
570	31.362	31.419	31.477	31.535	31.592	31.650	31.708	31.766	31.823	31.881	31.939	570
580	31.939	31.997	32.055	32.113	32.171	32.229	32.287	32.345	32.403	32.461	32.519	580
590	32.519	32.577	32.636	32.694	32.752	32.810	32.869	32.927	32.985	33.044	33.102	590
600	33.102	33.161	33.219	33.278	33.337	33.395	33.454	33.513	33.571	33.630	33.689	600
610	33.689	33.748	33.807	33.866	33.925	33.984	34.043	34.102	34.161	34.220	34.279	610
620	34.279	34.338	34.397	34.457	34.516	34.575	34.635	34.694	34.754	34.813	34.873	620
630	34.873	34.932	34.992	35.051	35.111	35.171	35.230	35.290	35.350	35.410	35.470	630
640	35.470	35.530	35.590	35.650	35.710	35.770	35.830	35.890	35.950	36.010	36.071	640
650	36.071	36.131	36.191	36.252	36.312	36.373	36.433	36.494	36.554	36.615	36.675	650
660	36.675	36.736	36.797	36.858	36.918	36.979	37.040	37.101	37.162	37.223	37.284	660
670	37.284	37.345	37.406	37.467	37.528	37.590	37.651	37.712	37.773	37.835	37.896	670
680	37.896	37.958	38.019	38.081	38.142	38.204	38.265	38.327	38.389	38.450	38.512	680
690	38.512	38.574	38.636	38.698	38.760	38.822	38.884	38.946	39.008	39.070	39.132	690

Thermocouple Types

Type	**Positive wire** *characteristic*	**Negative wire** *characteristic*	Plug	**Temp. range**
T	Copper (blue) *yellow colored*	Constantan (red) *silver colored*	Blue	-300 to 700 °F
J	Iron (white) *magnetic, rusty?*	Constantan (red) *non-magnetic*	Black	32 to 1400 °F
E	Chromel (violet) *shiny finish*	Constantan (red) *dull finish*	Violet	32 to 1600 °F
K	Chromel (yellow) *non-magnetic*	Alumel (red) *magnetic*	Yellow	32 to 2300 °F
N	Nicrosil (orange)	Nisil (red)	Orange	32 to 2300 °F
S	Pt90% - Rh10% (black)	Platinum (red)	Green	32 to 2700 °F
B	Pt70% - Rh30% (grey)	Pt94% - Rh6% (red)	Grey	32 to 3380 °F

Thermocouple Extension Type	ANSI	BS	DIN	NFC	JIS	IEC
JX + Iron − Constantan						
KX + Chromel − Alumel						
TX + Copper − Constantan						
EX + Chromel − Constantan						
NX + Nicrosil − Nisil			* SEE BELOW	* SEE BELOW	* SEE BELOW	
SX + Copper − Alloy 11						

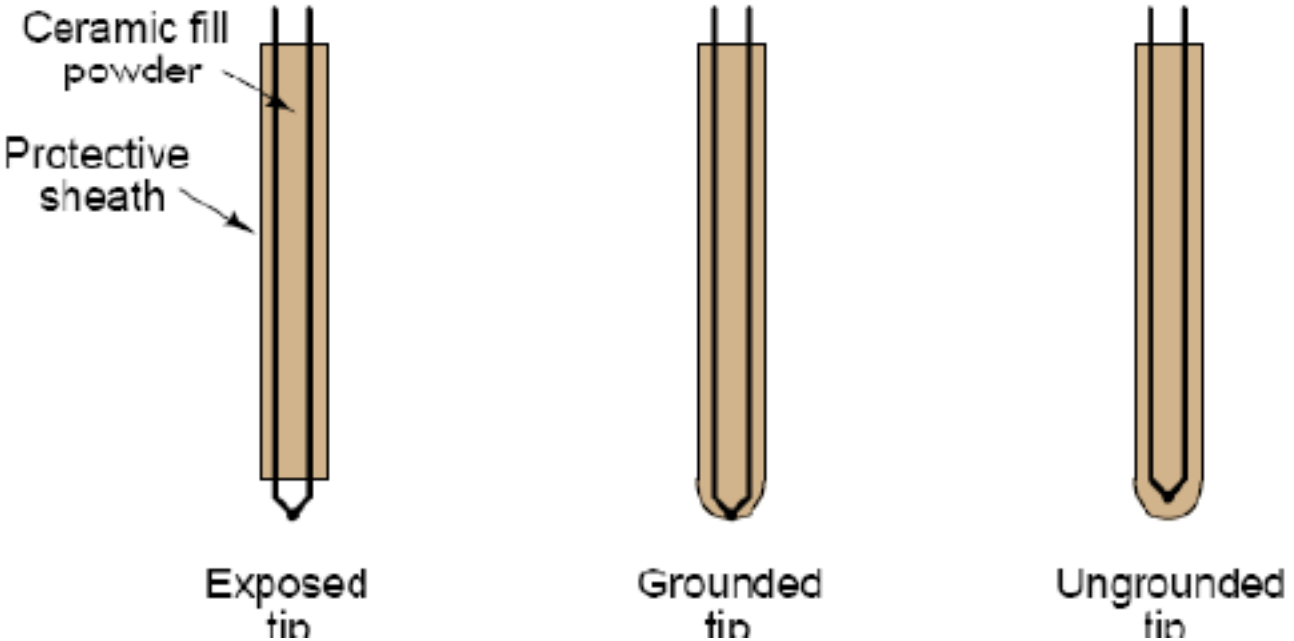
T.


Millivolts
+80
+70
+60
+50
+40
+30
+20
+10
0
-10
Type 'E'
Iron verses Constantan
(Type 'J')
Chromel verses Alumel
(Type 'K')
Nicrosil verses Nisil
Platinum/13% Rhodium
Rhodium verses Platinum
(Type 'R')
Copper verses Constantan
(Type 'T')
Platinum/10% Rhodium
Rhodium verses Platinum
(Type 'S')
-200 0 200 400 600 800 1000 1200 1400 1600 1800 °C
-328 32 392 752 1112 1472 1832 2192 2552 2912 3272 °F

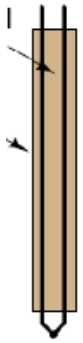
Three Basic Types Of Thermocouple Assembly

Some thermocouple assemblies are manufactured as follw:

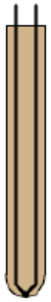
- Ground junction
- Ungrounded junction
- Exposed junction

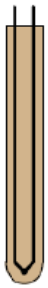


Thermocouple Assembly Types

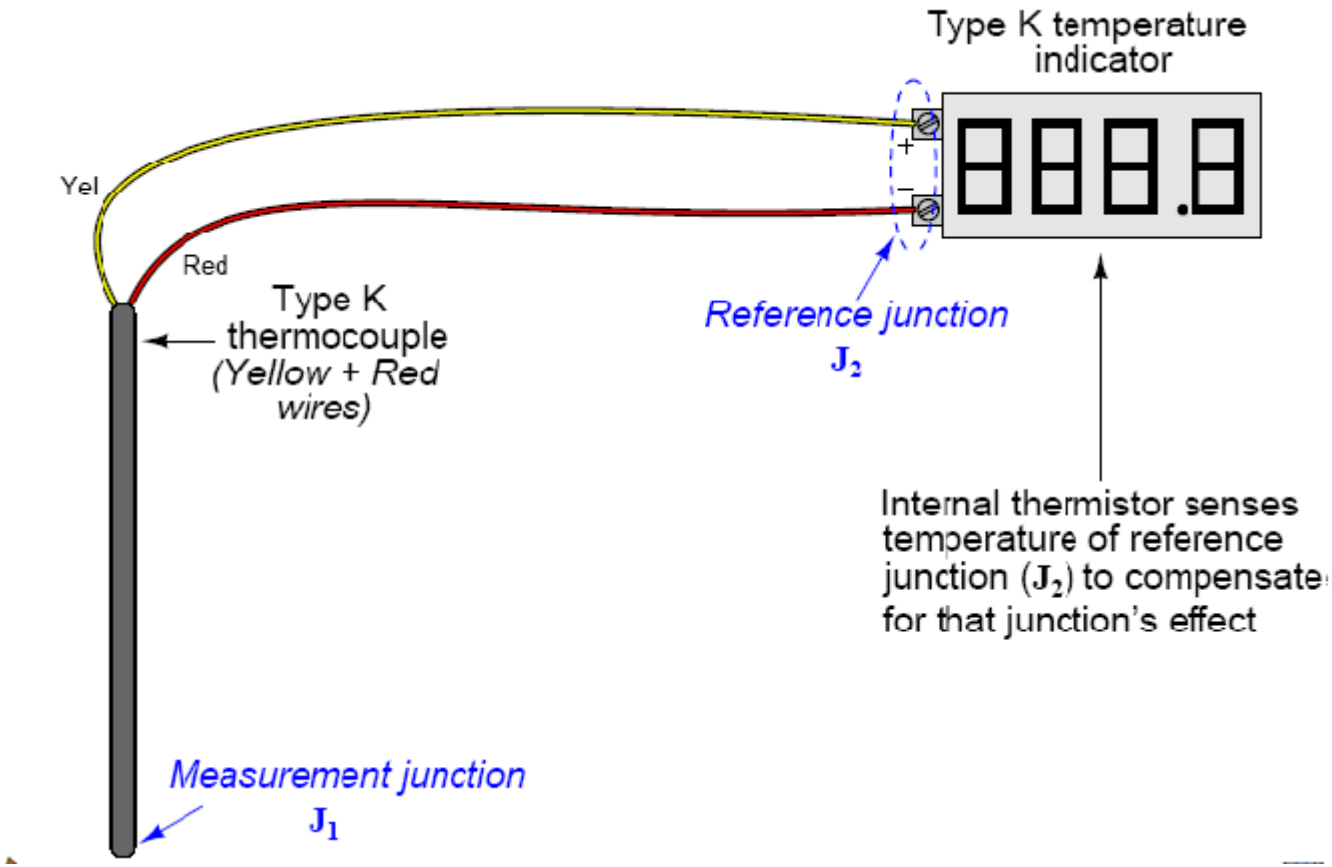


- The exposed junction is often used for the measurement of static or flowing non-corrosive gas temperatures where the response time must be minimal.
  - Exposed hot junction is susceptible to oxidation and corrosion. Thermowell may be used to protect it but that will cause higher response time.
- The grounded junction often is used for the measurement of static or flowing corrosive gas and liquid temperatures and for high-pressure applications.
  - Protects the sensor but Increases response time. Sensor more susceptible to electromagnetic induction (EMI).
  - Increases conduction and radiation errors.
- The ungrounded junction often is used for the measurement of static or flowing corrosive gas and liquid temperatures in critical electrical applications.
  - Influence of EMI lesser
  - Larger conduction and radiation errors

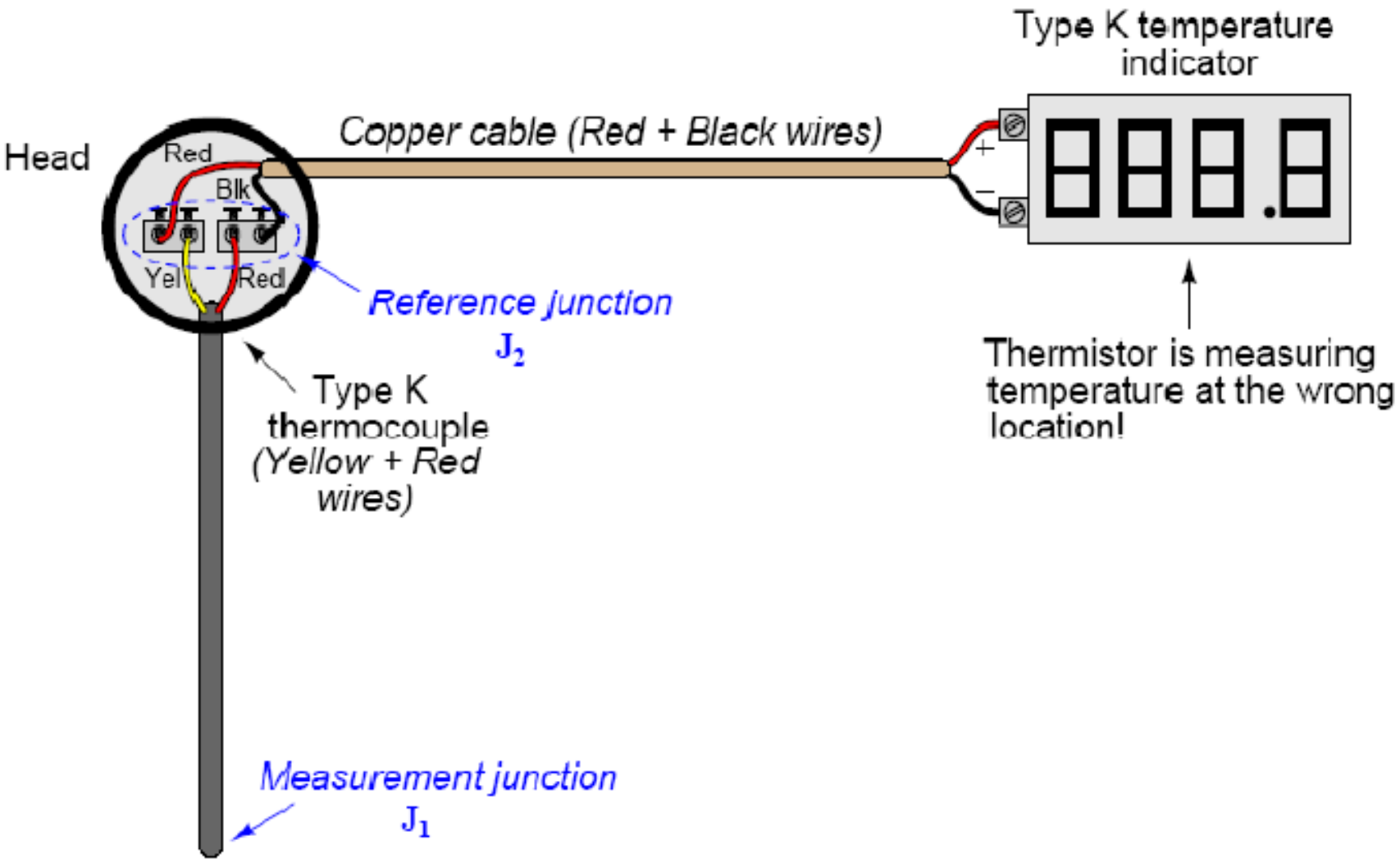




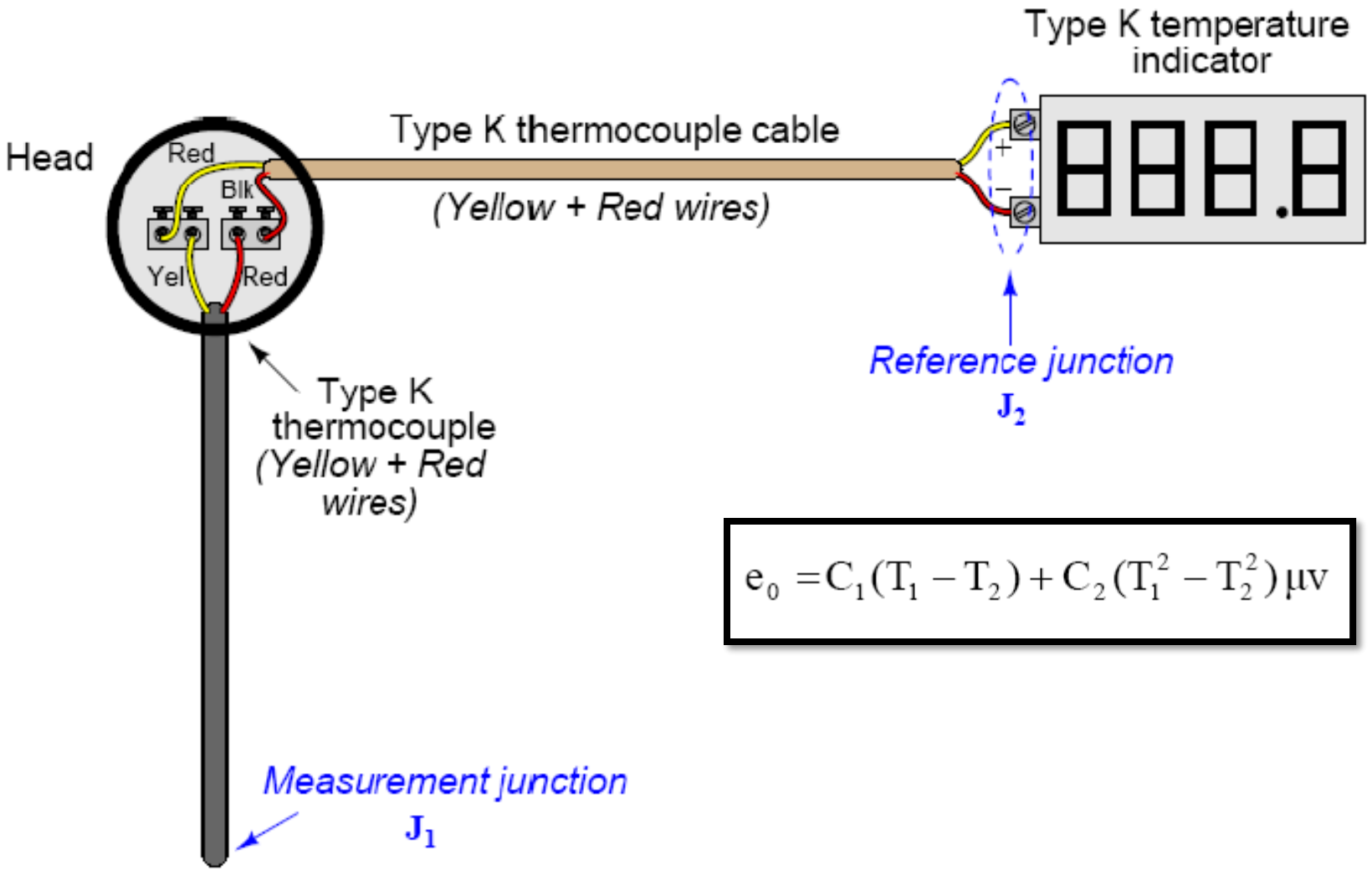
Thermocouple Circuit Arrangement



Thermocouple Circuit Arrangement



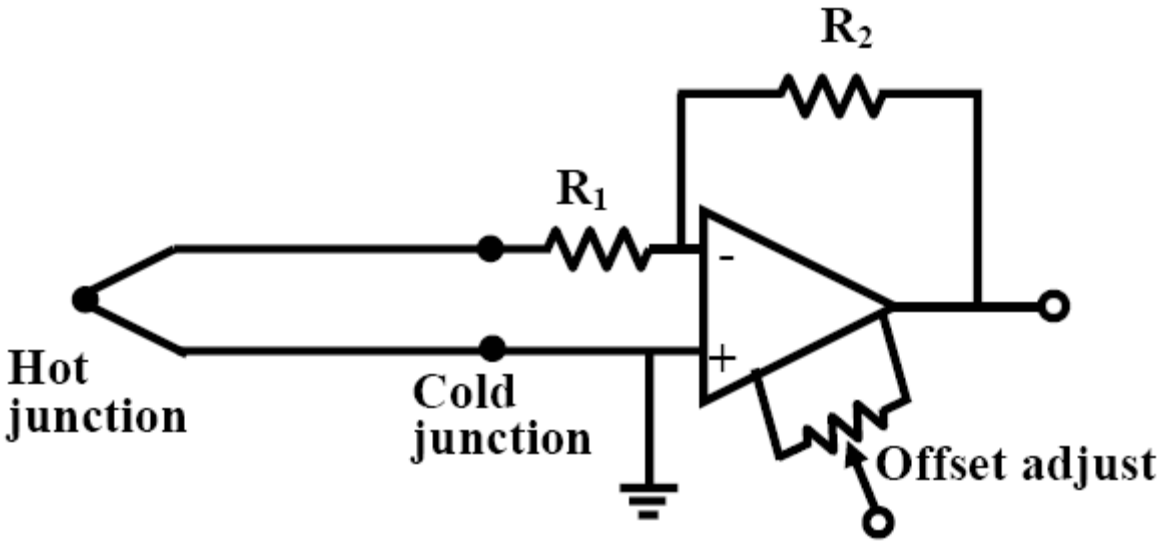
Thermocouple Circuit Arrangement



$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$

Reference Junction Compensation

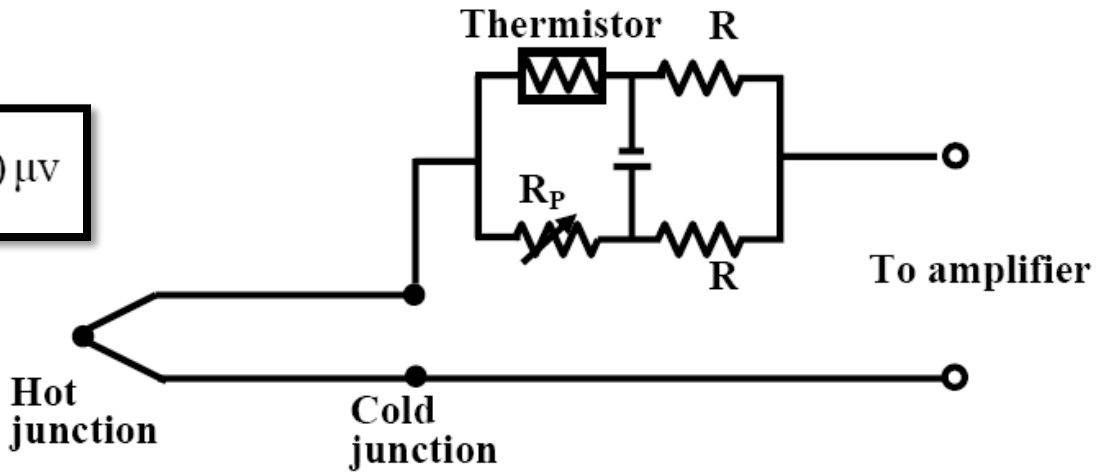
- thermocouple output voltage will vary if the reference junction temperature changes.
- it is desirable that the cold junction of the thermocouple should be maintained at a constant temperature.
- Ice bath can be used for this purpose, but it is not practical solution for industrial situation
- An alter ure oven. A fixed vol le, to obtain the actu
- But the at ambient tempera
- For high of reference junction e measuring 1500°C,)
- Here a c ded through the offset of the op-amp. The thermocouple voltage is also amplified by the same op-amp



Reference Junction Compensation

- A more accurate method is the use of a thermistor, or a RTD to measure the ambient temperature and compensate the error through a bridge circuit.
- The bridge circuit is balanced at 0°C. When the ambient temperature goes above 0°C, the emf generated in the thermocouple is reduced; at the same time bridge unbalanced voltage is added to it in order to maintain the overall voltage at the same value.

$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$



Thermocouples

Advantages

- Simple, Rugged
- High temperature operation
- Low cost
- No resistance lead wire problems
- Point temperature sensing
- Fastest response to temperature changes

Disadvantages

- Least stable, least repeatable
- Low sensitivity to small temperature changes
- Extension wire must be of the same thermocouple type else compensation will be incorporated
- Wire may pick up radiated electrical noise if not shielded
- Lowest accuracy
- Susceptible to corrosiveness

Class Quiz

A thermocouple has a linear sensitivity of 30μv/°C, calibrated at a cold junction temperature of 0°C. It is used measure an unknown temperature with the cold junction temperature of 30°C. Find the actual hot junction temperature if the emf generated is 3.0 mv.

$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$

- Ans: 130 °C

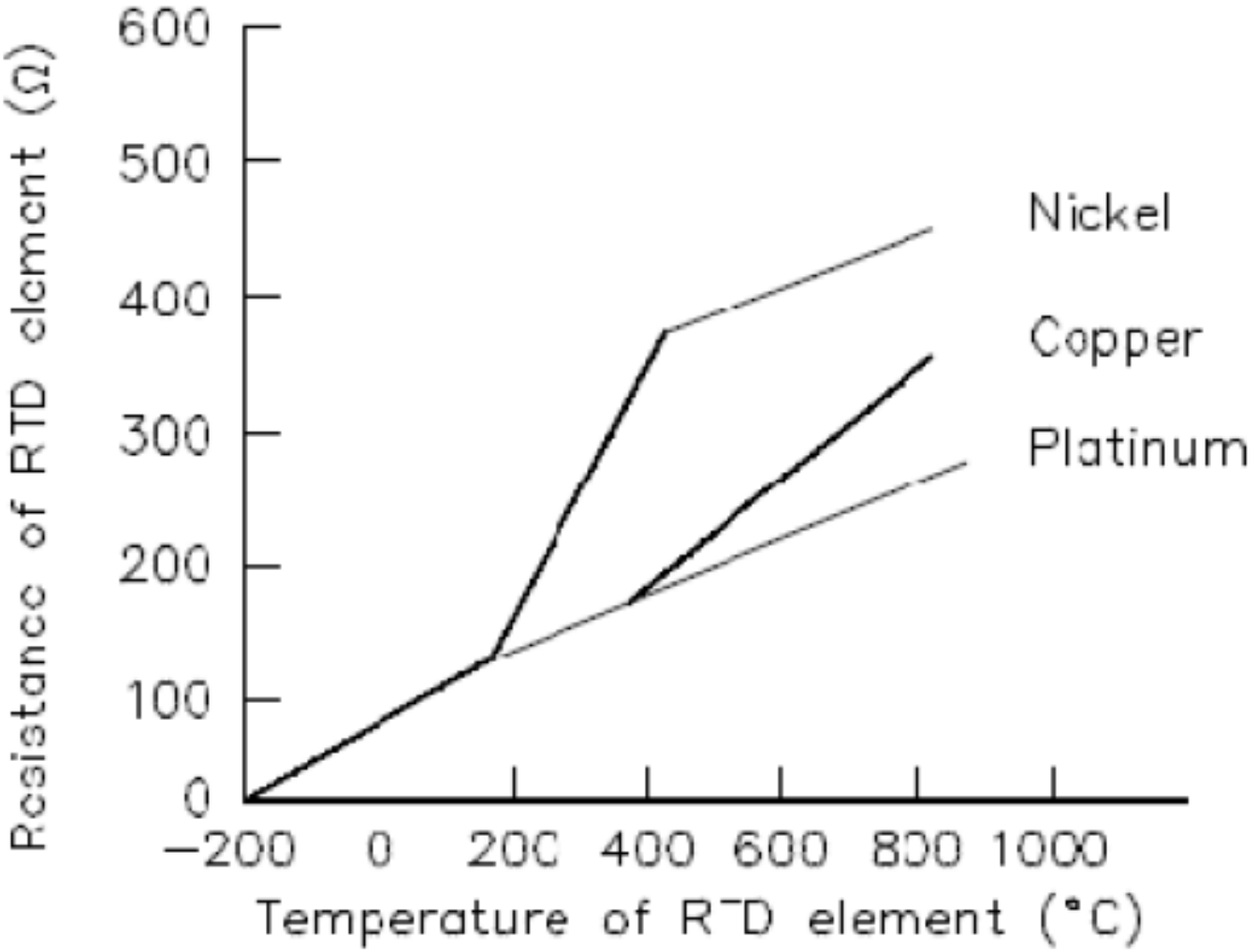
RTD

(Resistance Temperature Detector)

Historical Perspective

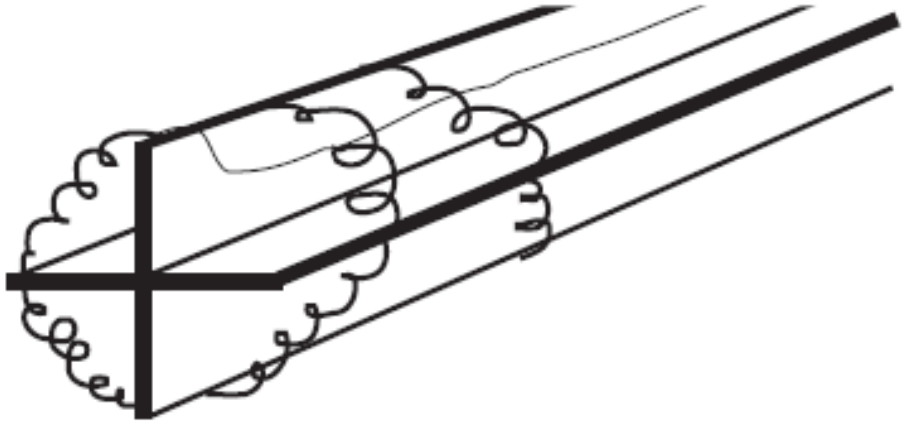
- The same year that Seebeck made his discovery about thermoelectricity, Sir Humphrey Davy announced that the resistivity of metals showed a marked temperature dependence.
- Fifty years later, Sir William Siemens proffer the use of platinum as the element in a resistance thermometer.
  - His choice proved most favorable, as platinum is used to this day as the primary element in all high-accuracy resistance thermometers.

Why Platinum?



First Commercial Grade RTD

- The classical resistance temperature detector (RTD) construction using platinum was proposed by C.H. Meyers in 1932.
  - He wound a helical coil of platinum on a crossed mica web and mounted the assembly inside a glass tube.
  - This construction minimized strain on the wire while maximizing resistance.



Platinum Sensing Resistors

- Platinum, with its wide temperature range and stability, has become the preferred element material for resistance thermometers.
- Platinum sensing resistors are available with alternative R_o values, for example 10, 25 and 100 Ohms.
- The platinum sensing resistor, Pt100 to IEC 751 is dominant in many parts of the world.
  - Its advantages include chemical stability, relative ease of manufacture, the availability of wire in a highly pure form and excellent reproducibility of its electrical characteristic.
- The result is a truly interchangeable sensing resistor which is widely commercially available at a reasonable cost.

RTD Applications

- Consumer applications
  - Automotive
  - Thermostats
  - Small appliances
  - Ovens
  - Refrigerators
  - Air conditioners
  - Furnaces
  - Water heaters
- Industrial applications
  - Process control
  - Electronic circuits and assemblies
  - Printers
  - Laptops
  - Computers
  - Power supplies
  - Batter packs
  - Motor and bearing temperature
  - HVAC
  - Instruments and environmental chambers
- Medical applications
  - Respiratory, culture, incubator, and disposables

RTDs

Advantages

- Most stable over time
- Most accurate ±0.5 °C (±0.9°F)
- Most repeatable temperature measurement (less than 0.1% drift in 5 years)
- Very resistant to contamination/corrosion of the RTD element
- Substantial output voltage: 1 to 6 volts
- Compensation: not required
- Size: generally smaller than thermocouples

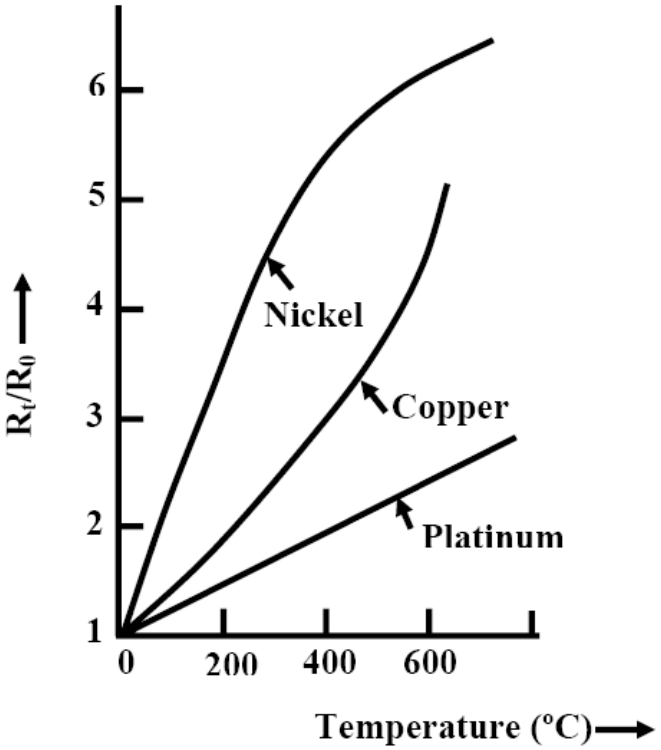
Disadvantages

- High cost (higher than thermocouples)
- Slowest response time
- Low sensitivity to small temperature changes
- Sensitive to vibration (strains the platinum element wire)
- Somewhat fragile
- Less rugged: affected by high temperatures and vibration.
- Lower temperature range:

RTD

$$R_t = R_0[1 + \alpha(t - t_0) + \beta(t - t_0)^2 + ...]$$

- Linearizing for lower temperature ranges



Resistance-temperature characteristics of metals

$$R_t = R_0[1 + \alpha(t - t_0)]$$

For Copper, $\alpha = 0.00427/^\circ C$.

RTD Construction

- The resistance wire is often put in a stainless steel well for protection against mechanical hazards. This is also useful from the point of view of maintenance, since a defective sensor can be replaced by a good one while the plant is in operation.
- Heat conducting but electrical insulating materials like mica is placed in between the well and the resistance material.
- The resistance wire should be carefully wound over mica sheet so that no strain is developed due to length expansion of the wire

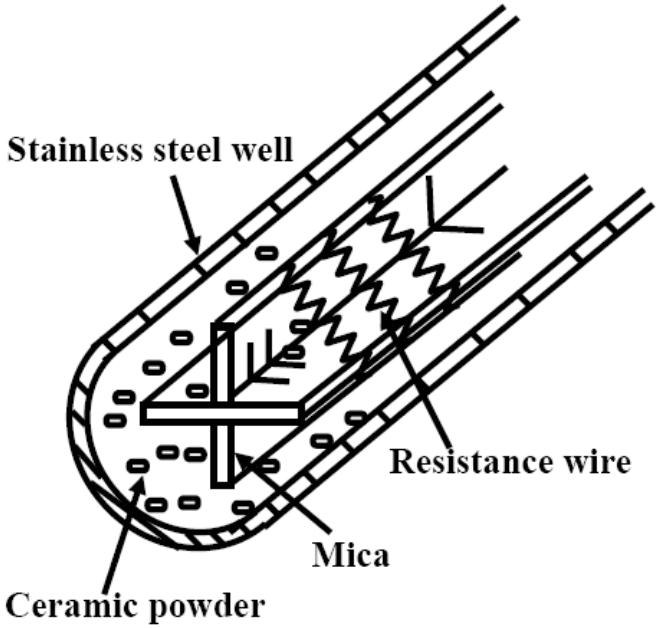
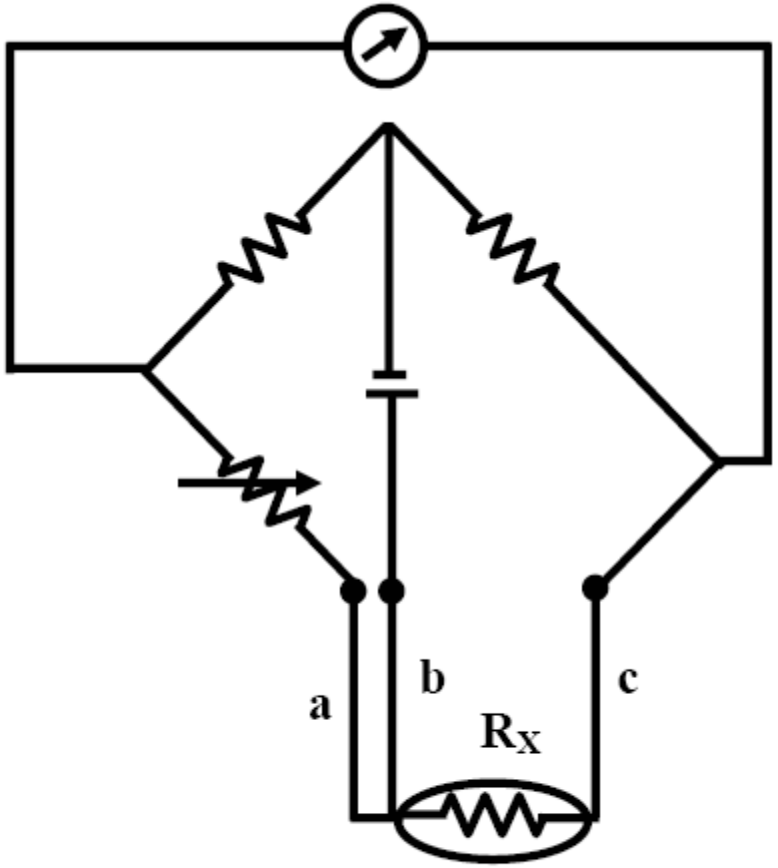


Fig. 2 Construction of an industrial RTD

RTD Measurement & Compensation

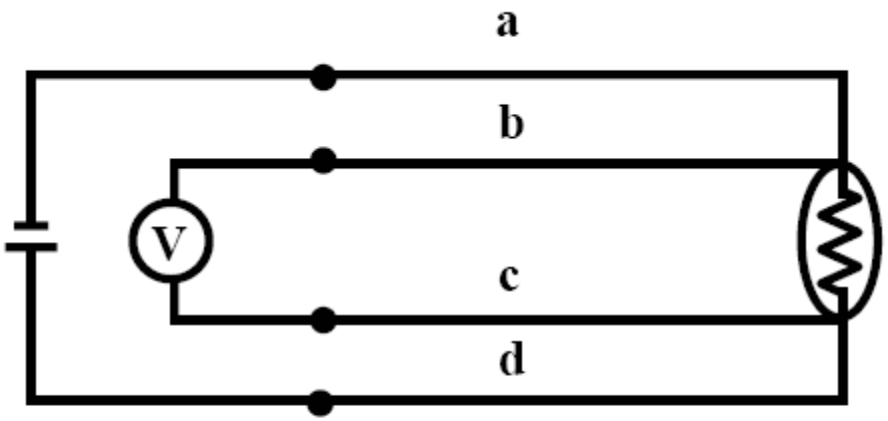
- The resistance variation of the RTD can be measured by a bridge, or directly by volt-ampere method.
  - But the major constraint is the contribution of the lead wires in the overall resistance measured.
  - Since the length of the lead wire may vary, this may give a false reading in the temperature to be measured.
- There must be some method for compensation so that the effect of lead wires is resistance measured is eliminated.
  - This can be achieved by using either a three wire RTD, or a four wire RTD.
- In three wire method one additional dummy wire taken from the resistance element and connected in a bridge (Figure) so that the two lead wires are connected to two adjacent arms of the bridge, thus canceling each other's effect.
- In another figure, the four wire method of measurement is shown. It is similar to a four terminal resistance and two terminals are used for injecting current, while two others are for measuring voltage.

Lead Wire Compensation through 3-wire & 4-wire Connection



a. b. c: lead wires

Fig. 3(a) Three wire RTD



a. b. c: lead wires

Fig. 3(b) Four wire RTD

Two-Wire RTD

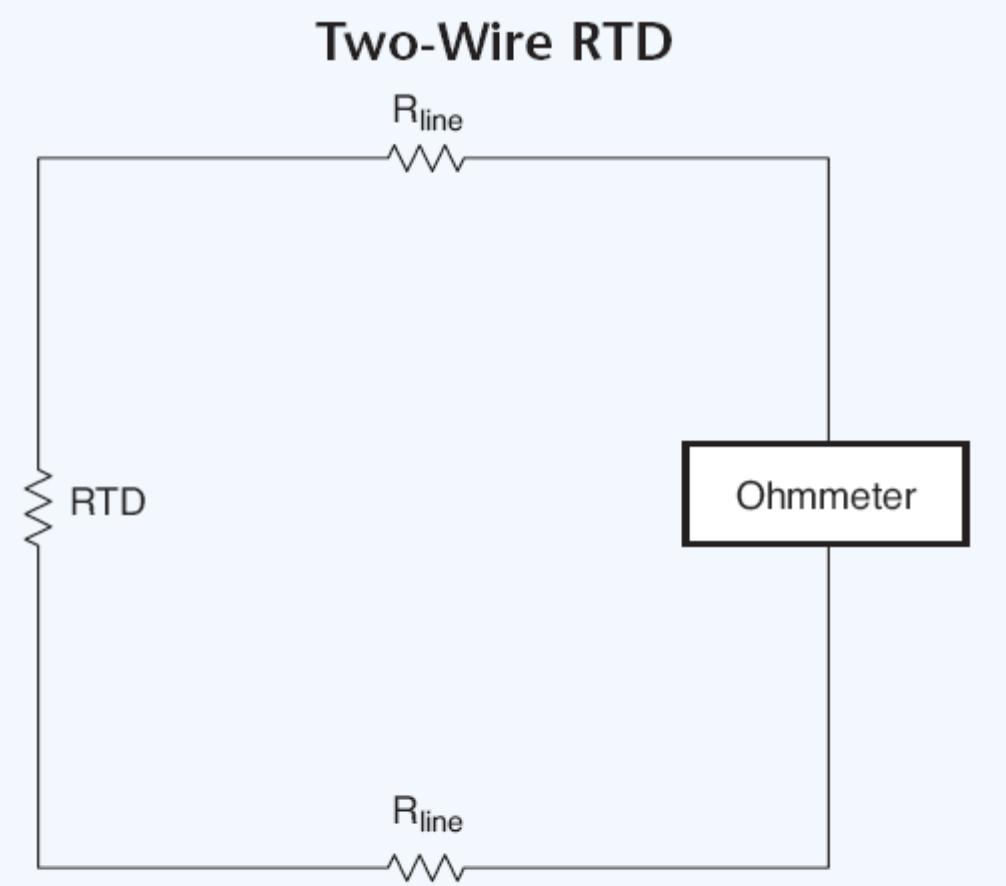


Fig. 6.12. The simplest arrangement for an RTD measurement is a simple series circuit containing only two wires connected to an ohmmeter.

3-Wire RTD Connection

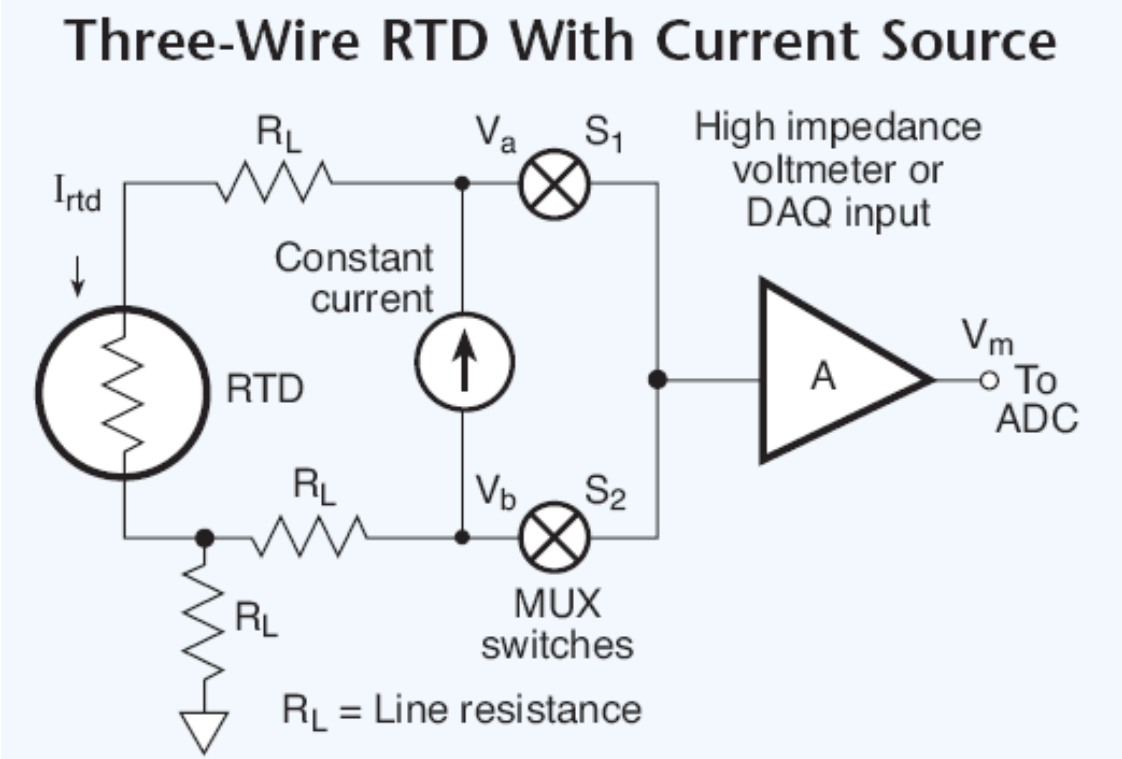


Fig. 6.14. The three-wire RTD method with a current supply is similar to the four-wire method. It simply eliminates one additional wire. Measure V_a first, then measure V_b.

Equation 6.04. 3-Wire RTD With Current Source

$$R_{rtd} = \frac{(V_a - V_b)}{I_{rtd}}$$

Four-Wire RTD Connection

Equation 6.03. 4-Wire RTD With Current Source

$$R_{rtd} = \frac{V_m}{I_{rtd}}$$

Where:

R_{rtd} = RTD resistance, Ω

V_m = Voltmeter reading, V

I_{rtd} = RTD current, A

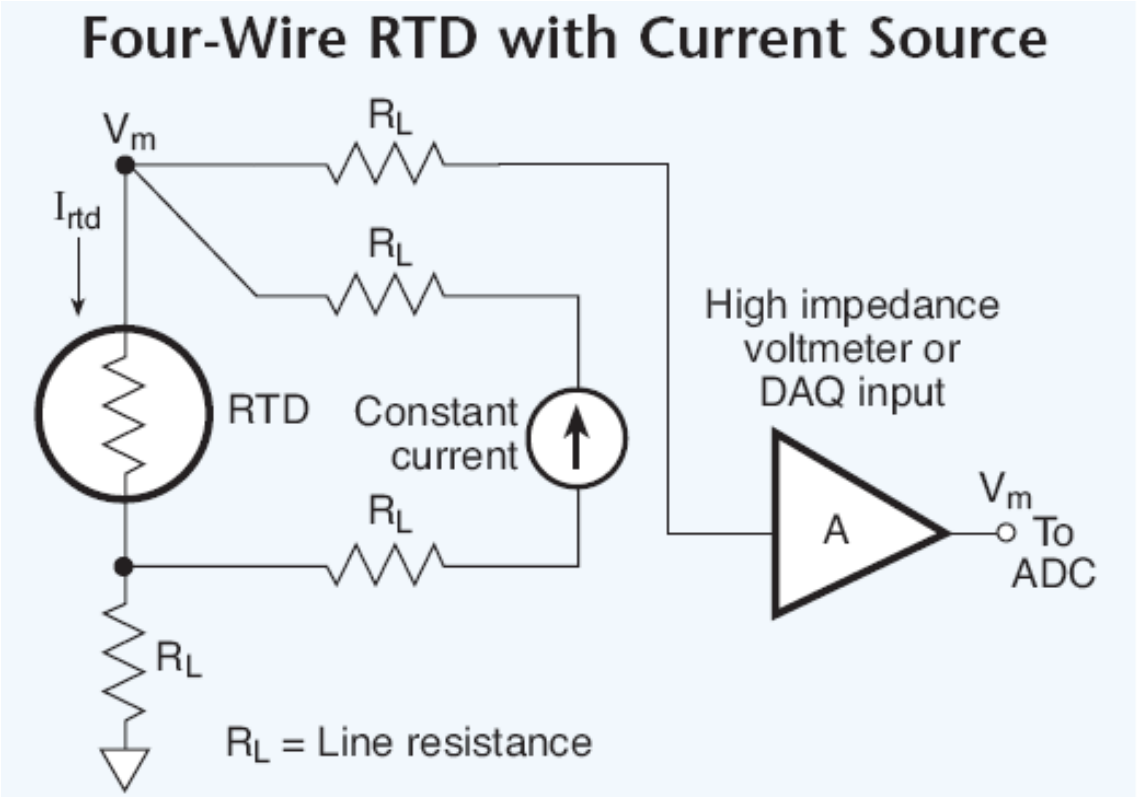


Fig. 6.13. *The four-wire RTD method with a current supply eliminates the lead wire resistance as a source of error.*

RTD

- Self Heating Issue
  - Current is provided to measure the resistance change.
  - This current produces I^2R losses
  - Creating self-heating effect

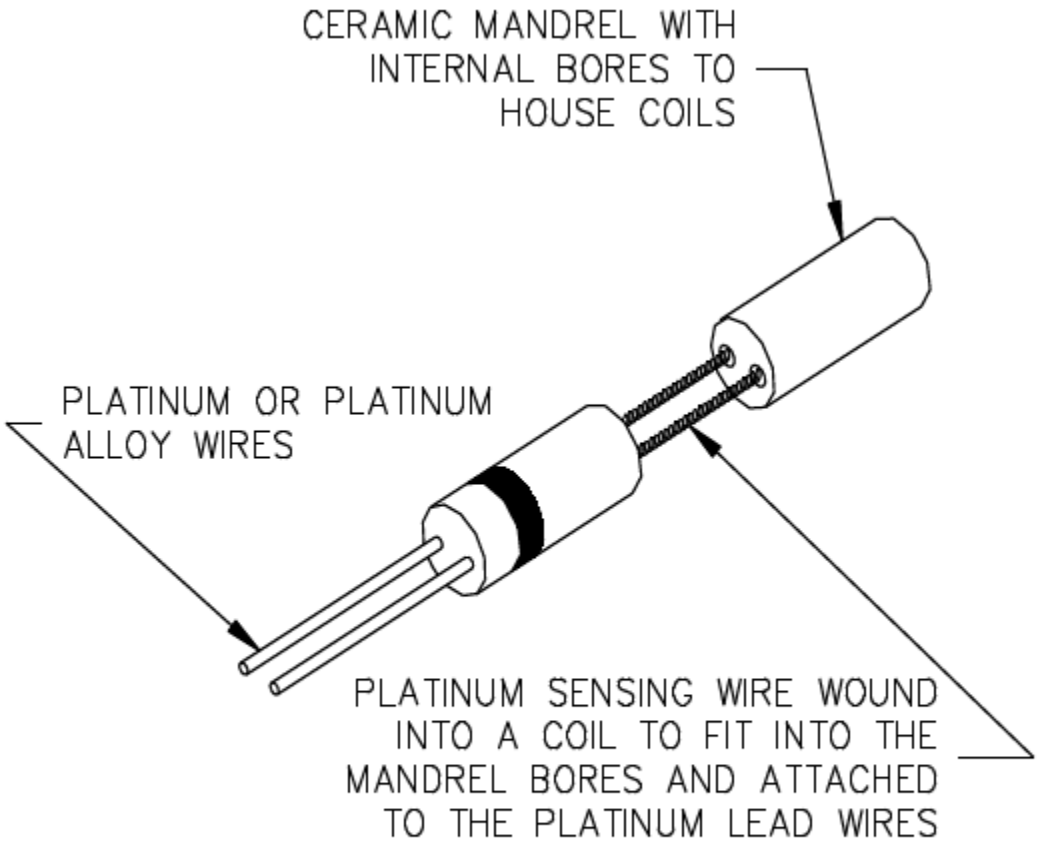
More on RTDs

- Wire Wound Measurement Element
- Film Type Measurement Element

Wire Wound Element

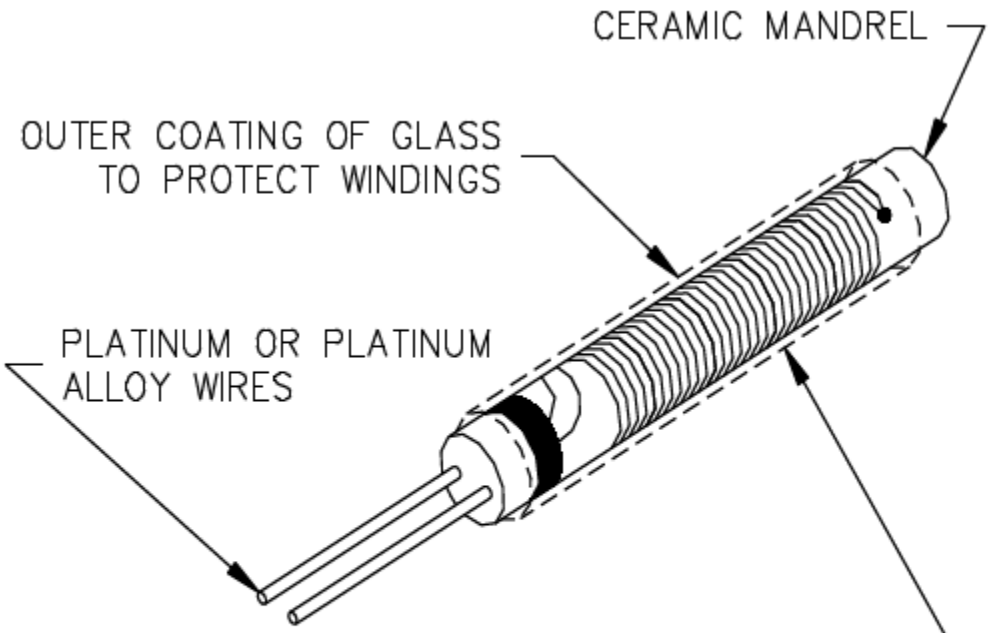
- Wire wound elements contain a length of very small diameter wire (typically .0005 to .0015 inch diameter) which is either wound into a coil and packaged inside a ceramic mandrel, or wound around the outside of a ceramic housing and coated with an insulating material.
- Larger lead wires (typically .008 to .015 inch diameter) are provided which allow the larger extension wires to be connected to the very small element wire.

Wire Wound Element RTD Design-1



WIRE WOUND ELEMENT – COILED DESIGN

Wire Wound Element RTD- Design 2

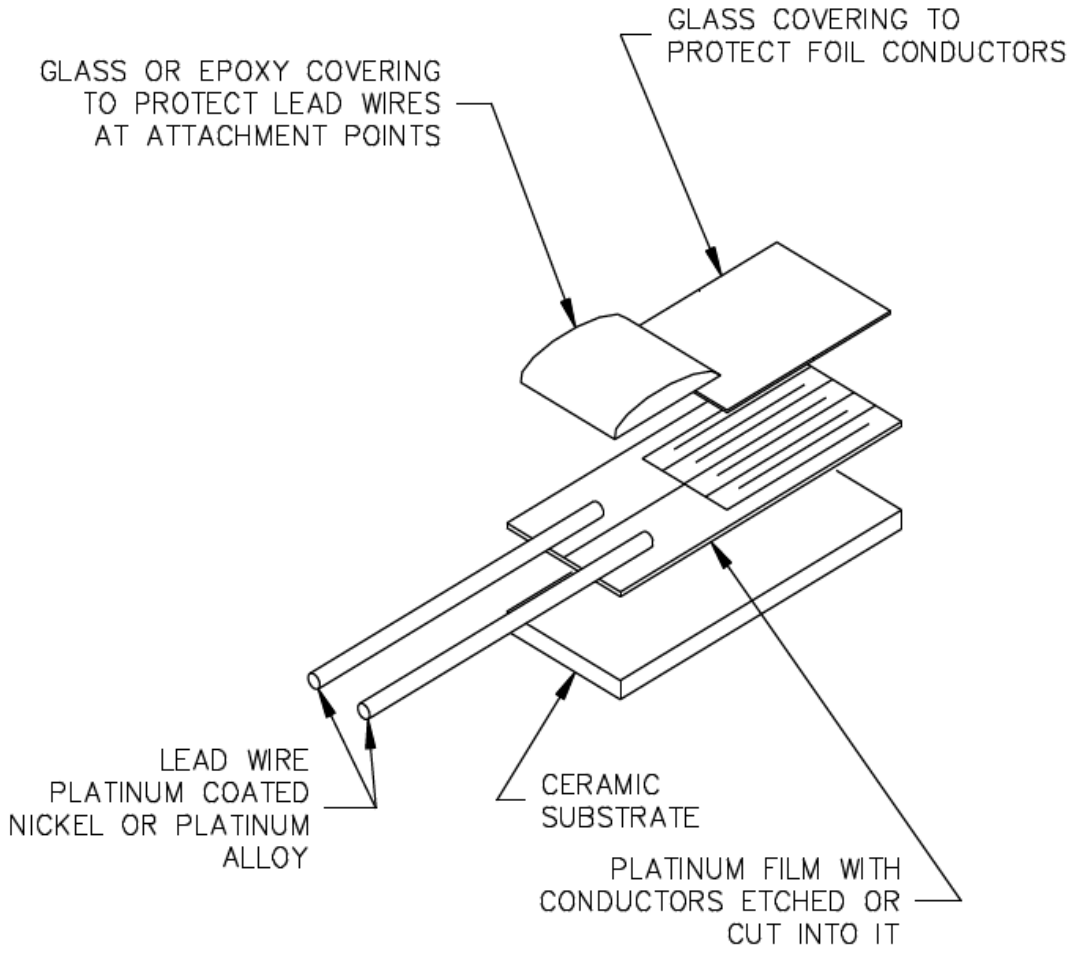

CERAMIC MANDREL
OUTER COATING OF GLASS TO PROTECT WINDINGS
PLATINUM OR PLATINUM ALLOY WIRES
PLATINUM SENSING WIRE WOUND AROUND MANDREL. ENDS FUSED AT TIP AND ATTACHED TO PLATINUM WIRES AT OTHER END

WIRE WOUND ELEMENT – OUTER WOUND DESIGN

Film Type Element RTD

- Film type sensing elements are made from a metal coated substrate which has a resistance pattern cut into it.
- This pattern acts as a long, flat, skinny conductor, which provides the electrical resistance.
- Lead wires are bonded to the metal coated substrate and are held in place using a bead of epoxy or glass.

Film Type Element RTD



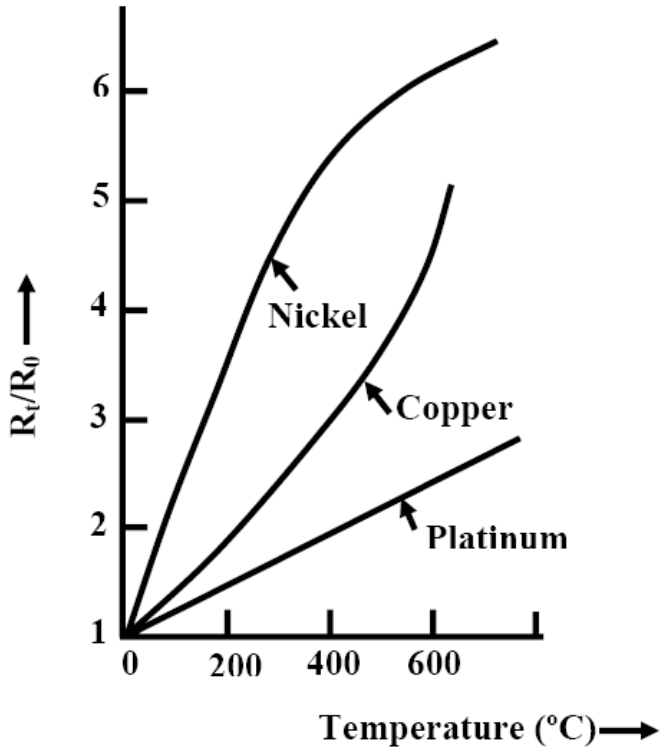
FILM STYLE ELEMENT

Quiz Problem

PT-100 is a Platinum RTD whose resistance at 0°C is 100Ω. If the resistance temperature co-efficient of Platinum is $3.91X10^{-3}$ /°C, then find its resistance at 100°C.

$$R_t = R_0[1 + \alpha(t - t_0)]$$

- 139 °C

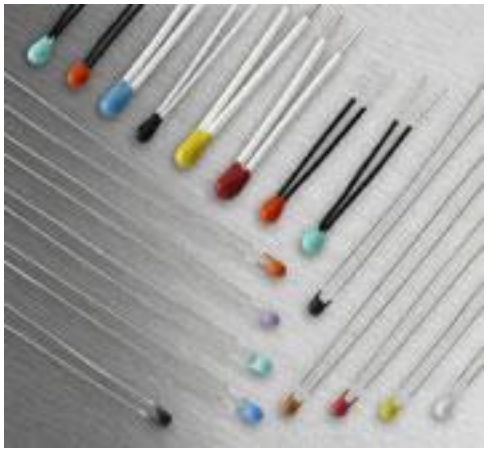


Resistance-temperature characteristics of metals

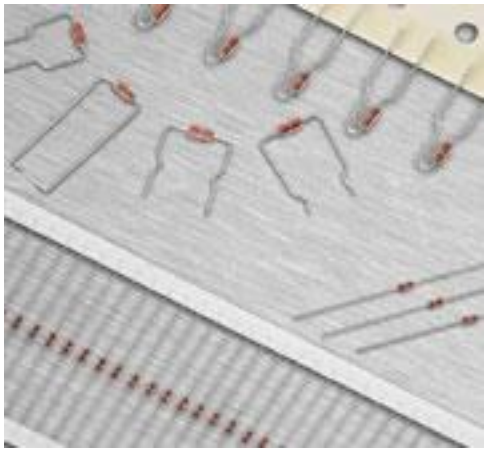
Thermistors

THERMal resISTORS

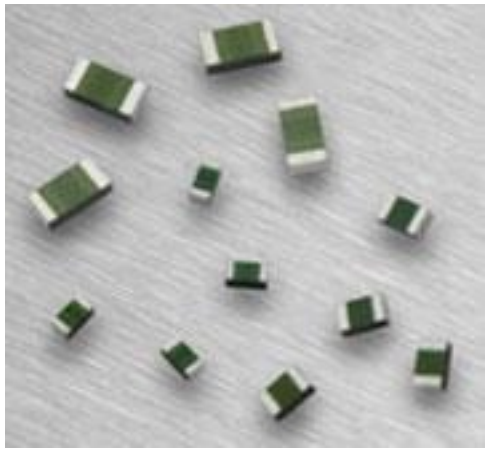
Thermistors are made of semiconductor materials (metallic compounds including oxides such as manganese, copper, cobalt, and nickel, as well as single-crystal semiconductors silicon and germanium).



Leads, coated



Glass encased



Surface mount

Thermistors
THERMal resISTORS

Assume a simple linear relationship between resistance and temperature for the following discussion:

$$\Delta R = k\,\Delta T$$

where

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance

Thermistors
THERMal resISTORS

Thermistors can be classified into two types depending on the sign of k.

If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor, Posistor.

If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor.

Thermistors - characteristics

- Thermistor is a resistor where resistance is strongly a function of temperature
- Important characteristics
  - Mass – larger masses = slower response
  - Temperature coefficient
    - NTC – Resistance decreases with temperature
      - Exponential relationship between temperature and resistance

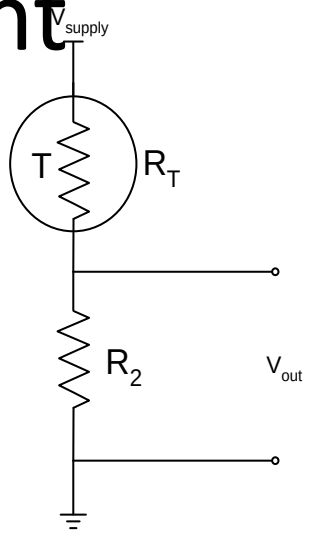
$$R_T = R_{T_0} e^{\left[\frac{\beta(T_0 - T)}{T_0 T}\right]}$$

    - PTC – Resistance increases with temperature
  - Packaging
  - Limited Temperature range

Thermistor circuits for temperature measurement

- Half bridge (voltage divider)

$$V_{\text{out}} = V_{\text{supply}} \frac{R_2}{\left[R_T + R_2\right]}$$



- For a NTC thermistor:

Variable	Symbol	Direction
Temperature	T	Increase
Thermistor resistance	R_T	Decrease
Voltage out	V_{out}	Increase

- Design issue: select V_{supply} so that self-heating is insignificant

Thermistors
THERMal resISTORS

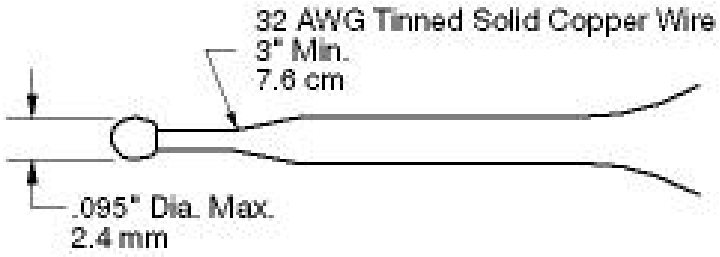
Thermistor Specifications

Interchangeability Tolerance (Accuracy):
± 0.2 °C (0 to 70 °C) Standard
± 0.1 °C (0 to 70 °C) XP Option

Dissipation Constant: 2.7 mW/°C

Stability (drift): Less than 0.02 °C / year

Sensor Type	Reference Resistance	Operating Range
1.8K	1.8 KΩ @ 25 °C	-55 to 150 °C
2.2K	2,252 KΩ @ 25 °C	-55 to 150 °C
3K	3 KΩ @ 25 °C	-55 to 150 °C
3.3K	3.3 KΩ @ 25 °C	-55 to 150 °C
10K-2	10 KΩ @ 25 °C	-55 to 150 °C
10K-3	10 KΩ @ 25 °C	-80 to 150 °C
10K-3(11K)	5.2 KΩ @ 25 °C	-80 to 150 °C
20K	20 KΩ @ 25 °C	-80 to 150 °C
47K	47 KΩ @ 25 °C	-80 to 150 °C
50K	50 KΩ @ 25 °C	-80 to 150 °C
100K	100 KΩ @ 25 °C	-80 to 150 °C

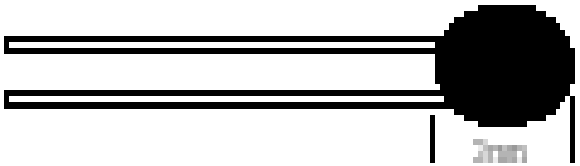


Thermistor-choice is based on the nominal resistance you want at the operating temperature range, on the size, and on the time constant.

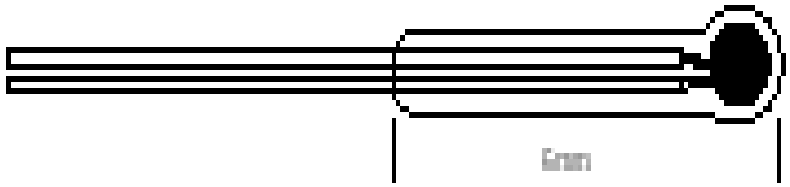
Time constants are about 5 - 10 seconds. (Check this out with your thermistor).

Thermistors

- Most are seen in medical equipment markets.
- Thermistors are also used are for engine coolant, oil, and air temperature measurement in the transportation industry.



a. Epoxy Coated Thermistor Bead.



b. Glass Coated Thermistor Bead.

Thermistors

Advantages

- High sensitivity to small temperature changes
- Temperature measurements become more stable with use
- Copper or nickel extension wires can be used

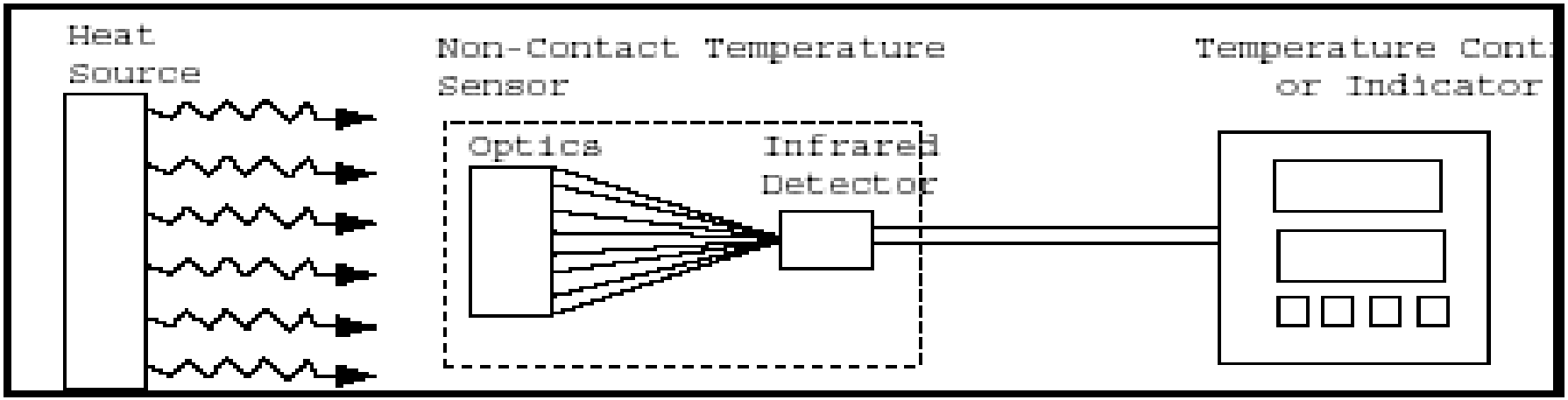
Disadvantages

- Limited temperature range
- Fragile
- Some initial accuracy “drift”
- Decalibration if used beyond the sensor’s temperature ratings

Infrared Sensors

- **An infrared sensor intercepts a portion of the infrared energy radiated by an object.**

- **Many types Optical Pyrometers, Radiation Pyrometers, Total Radiation Pyrometers, Automatic Infrared Thermometers, Ear Thermometers, Fiber optic Thermometers, Two-Color Pyrometers, Infra-Snakes, and many more.**



Infrared Applications

- **Manufacturing process like metals, glass, cement, ceramics, semiconductors, plastics, paper, textiles, coatings.**
- **Automation and feedback control**
- **Improve safety in fire-fighting, rescues and detection of criminal activities.**
- **Used to monitor and measure human body temperatures with one second time response.**
- **Reliability and maintenance needs from building heating to electrical power generation and distribution**

Infrared Sensors

Advantages

- No contact with the product required
- Response times as fast or faster than thermocouples
- No corrosion or oxidation to affect sensor accuracy
- Good stability over time
- High repeatability

Disadvantages

- High initial cost
- More complex - support electronics required
- Emissivity variations affect temperature measurement accuracy
- Field of view and spot size may restrict sensor application
- Measuring accuracy affected by dust, smoke, background radiation, etc.

Pressure Sensors

Pressure Sensors

- Pressure is the force per unit area that a liquid or gas exerts on its surroundings, such as the force or pressure of the atmosphere on the surface of the Earth, and the force that liquids exert on the bottom and walls of a container
- Pressure is not only an important parameter for process control, but also as an indirect measurement for other parameters.
- Not only is it important to select the right device for the required range and accuracy, but the device must be immune to contamination and interaction with the fluid being measured

Categorization of Pressure Measurements

- absolute pressure,
- gage pressure and
- Differential pressure

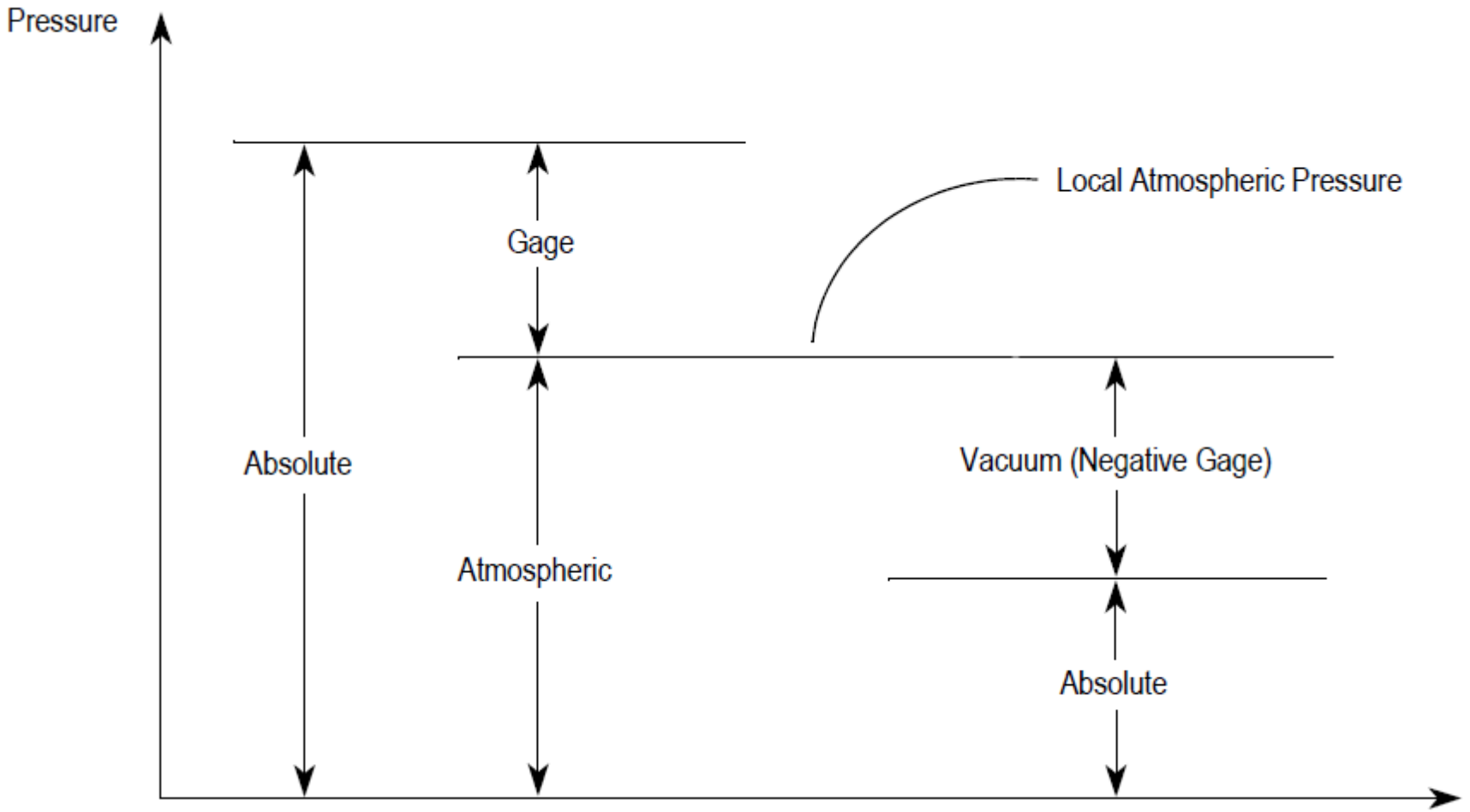
Absolute Pressure

- Absolute pressure refers to the absolute value of the force per-unit-area exerted on a surface by a fluid.
  - the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum.

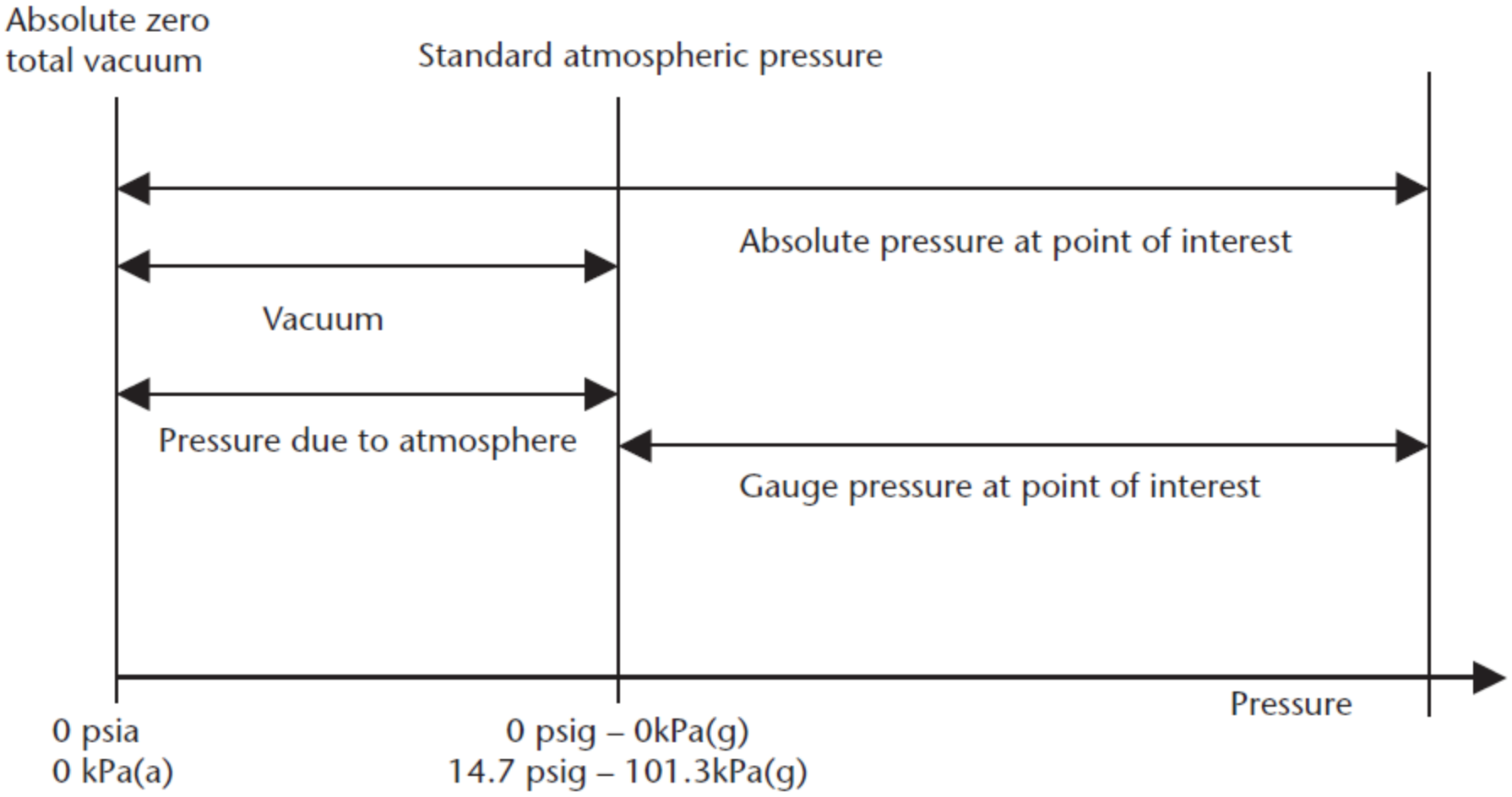
Gage Pressure

- Gage pressure is the measurement of the difference between the absolute pressure and the local atmospheric pressure.
  - Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The U.S. standard atmospheric pressure at sea level and 59°F (20°C) is 14.696 pounds per square inch absolute (psia) or 101.325 kPa absolute (abs).
- A gage pressure by convention is always positive.
- A negative' gage pressure is defined as vacuum. Vacuum is the measurement of the amount by which the local atmospheric pressure exceeds the absolute pressure.

Pressure Term Relationships



Gauge Pressure & Absolute Pressure

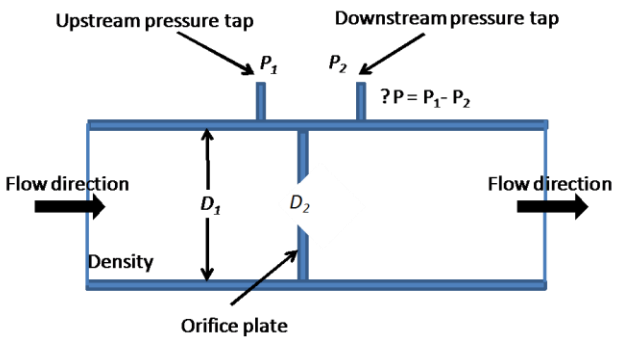


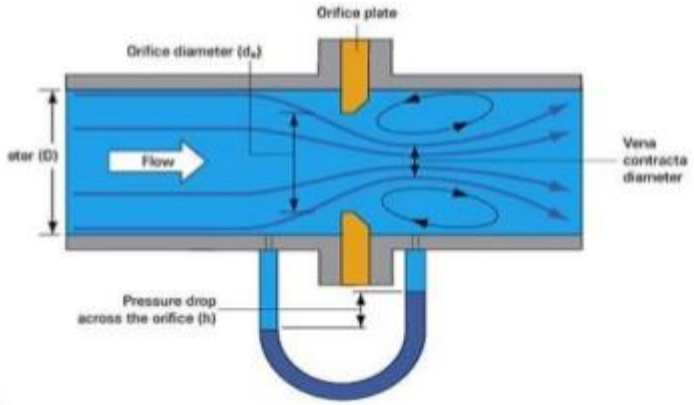
Conversion Table for Common Units of Pressure

	kPa	mm Hg	millibar	in H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kPa	1.000	7.50062	10.000	4.01475	0.145038
1 mm Hg	0.133322	1.000	1.33322	0.535257	0.0193368
1 millibar	0.1000	0.750062	1.000	0.401475	0.0145038
1 in H_2O	0.249081	1.86826	2.49081	1.000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.000
1 mm H_2O	0.009806	0.07355	9.8×10^{-8}	0.03937	0.0014223

Differential Pressure

- Differential pressure is simply the measurement of one unknown pressure with reference to another unknown pressure.
  - The pressure measured is the difference between the two unknown pressures.
  - This type of pressure measurement is commonly used to measure the pressure drop in a fluid system.





Fluid Pressure Types

- There are two types of fluid systems; *static systems and dynamic systems.*
- *A static system is one* in which the fluid is at rest and a dynamic system is on in which the fluid is moving.

Static Pressure Measurement

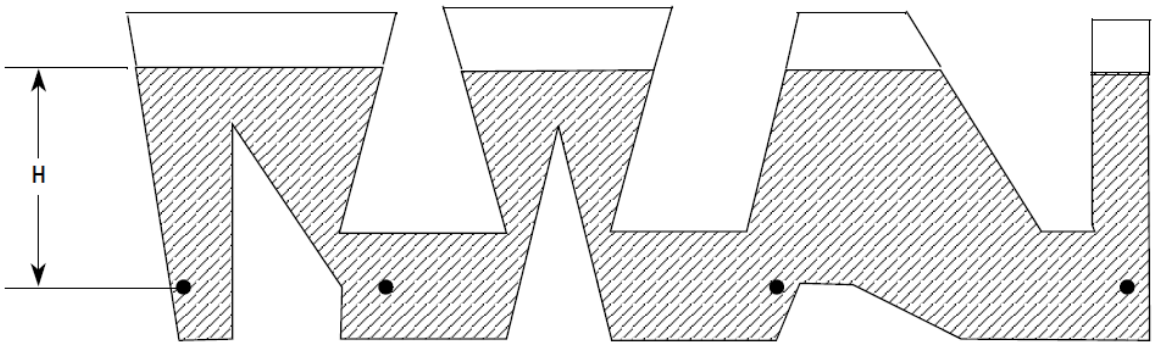


Figure 2. Continuous Fluid System

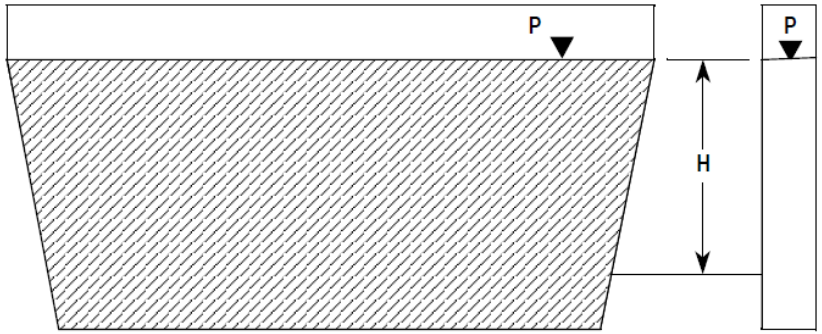


Figure 3. Pressure Measurement at a Depth in a Liquid

$$P_{abs} = P + (\rho \times g \times H)$$

Where:

P_{abs} is the absolute pressure at depth H.

P is the external pressure at the top of the liquid. For most open systems this will be atmospheric pressure.

ρ is the density of the fluid.

g is the acceleration due to gravity (g = 32.174 ft/sec^2 (9.81 m/sec^2)).

H is the depth at which the pressure is desired.

Dynamic Pressure Measurement

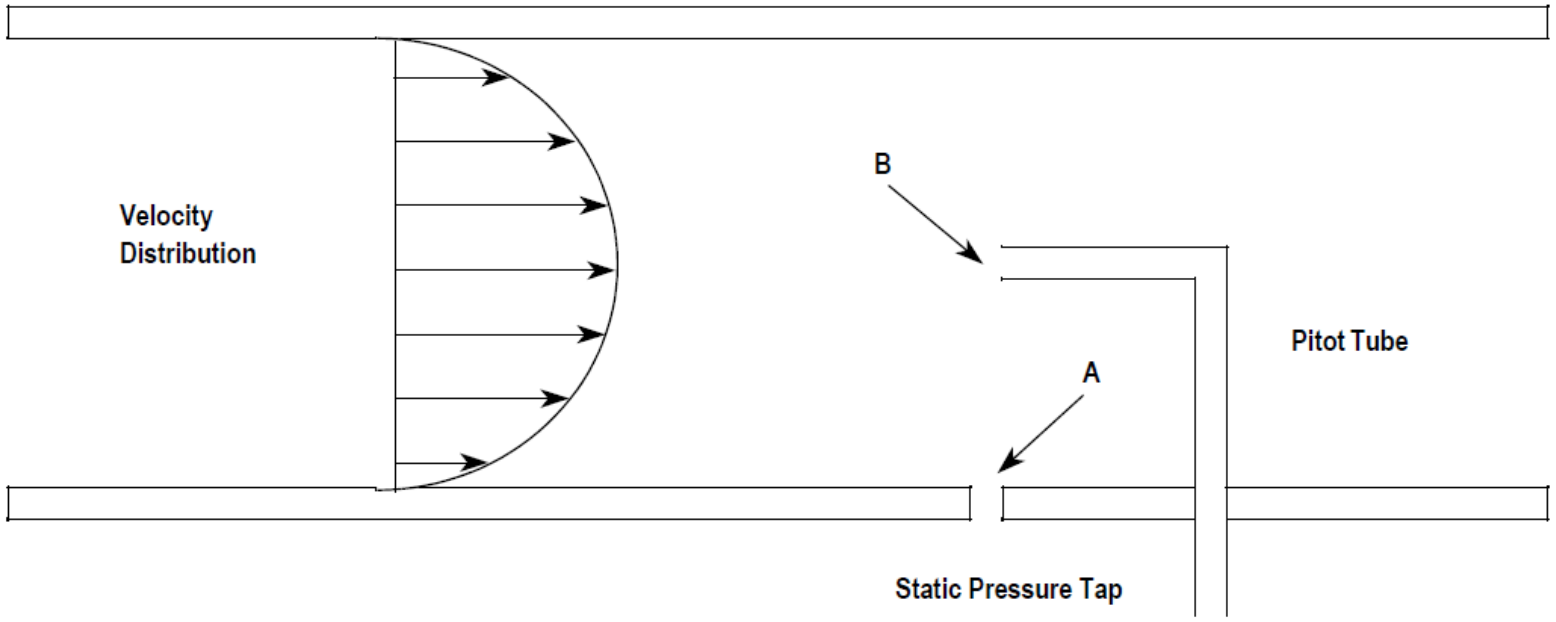
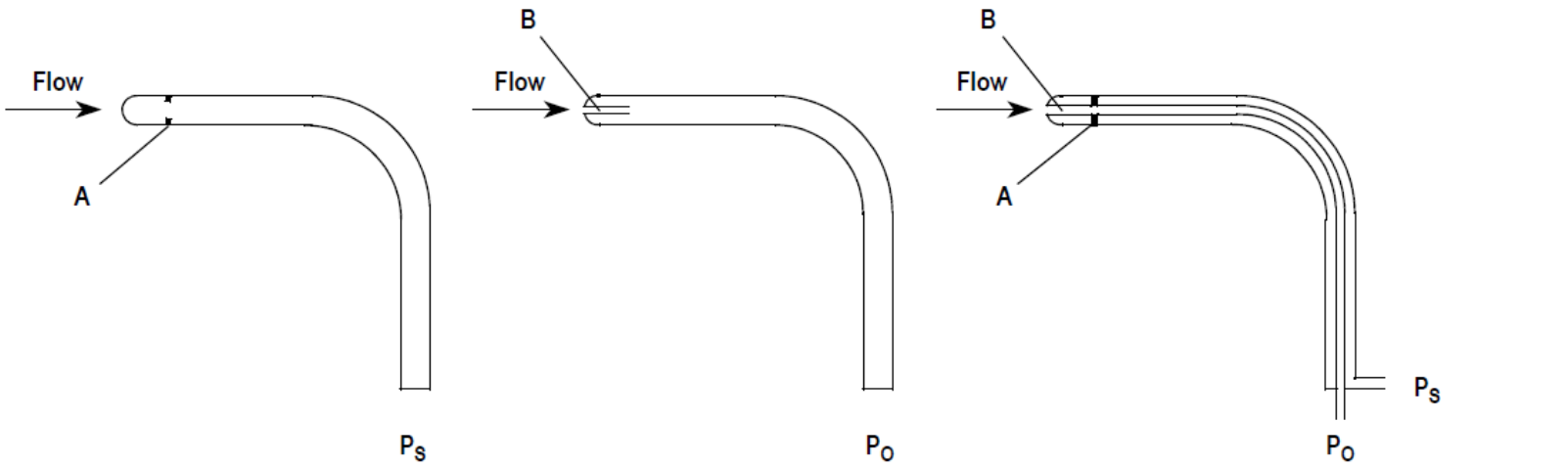


Figure 4. Static and Total Pressure Measurements Within a Dynamic Fluid System

Dynamic Pressure Measurement



(a) Static Pressure Probe

(b) Total Pressure Pitot Tube

(c) Combination Static Pressure and Total Pressure Pitot Tube (Pitot-Static Tube)

Figure 5. Types of Pressure Probes

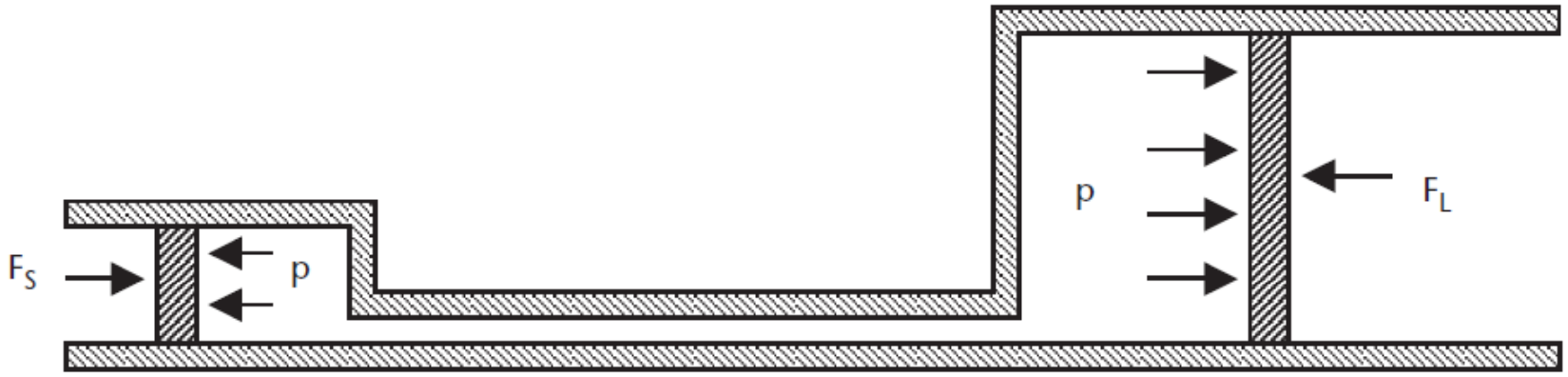
Pressure Head

- What is the pressure at the base of a water tower that has 35m of head?

$$p = 9.8\ \text{kN/m}^3 \times 35\text{m} = 343\ \text{kPa}$$

Hydraulic Pressure

In Figure 7.3, if the area of the small piston A_s is 8.2 in^2, and the area of the large piston A_L is 2.3 ft^2, what is the force F_L on the large piston, if the force F_s on the small piston is 25N?

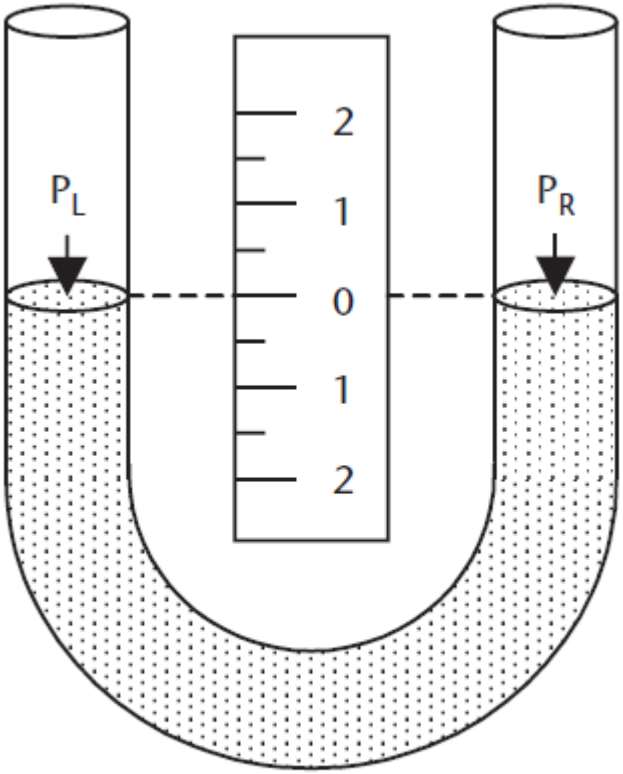


$$\text{Force } F_L \text{ on piston} = \frac{25N \times 2.3 \times 144}{8.2} = 1009.7N = 1.0097kN$$

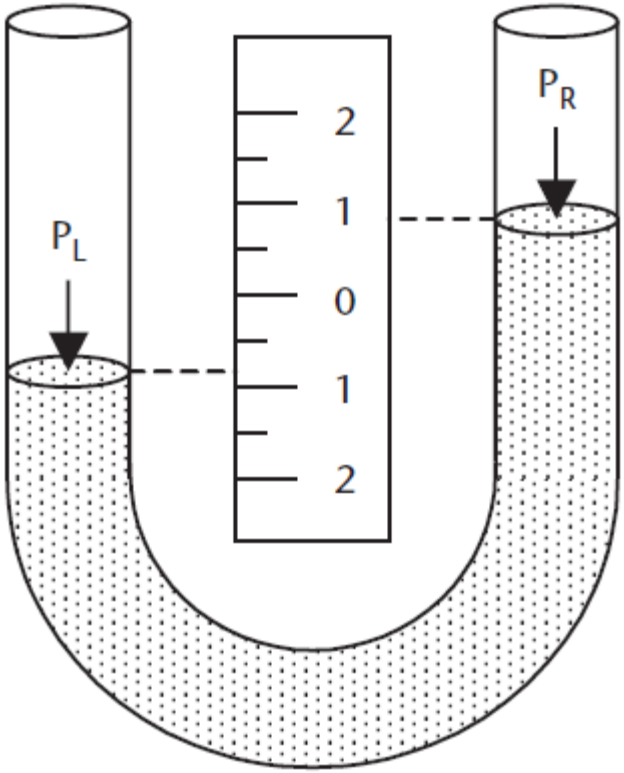
Measuring Instruments

- Pressure measuring devices:
  - U-tube manometers are being replaced with smaller and more rugged devices, such as the silicon diaphragm.
- Vacuum measuring devices
  - Require special techniques for the measurement of very low pressures vacuum measuring devices

U-Tube Manometer



$P_L = P_R$



$P_L > P_R$

Manometer Measurements

The liquid in a manometer has a specific weight of 8.5 kN/m^3. If the liquid rises 83 cm higher in the lower pressure leg, what is difference in the pressure between the higher and the lower legs?

$$\Delta p = \gamma \Delta h = 8.5 \times 83/100 \text{ kPa} = 7.05 \text{ kPa}$$

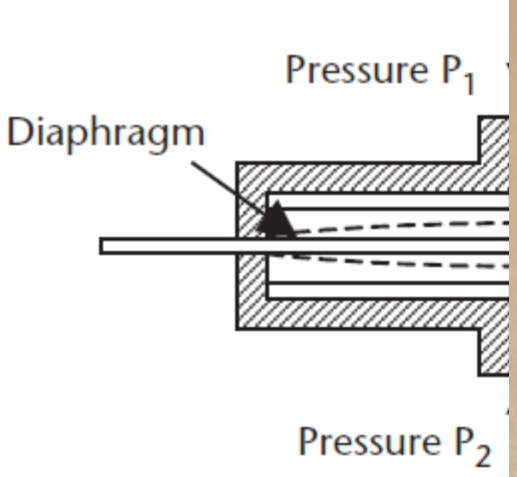
What is the liquid density in a manometer, if the difference in the liquid levels in the manometer tubes is 1.35m, and the differential pressure between the tubes is 7.85 kPa?

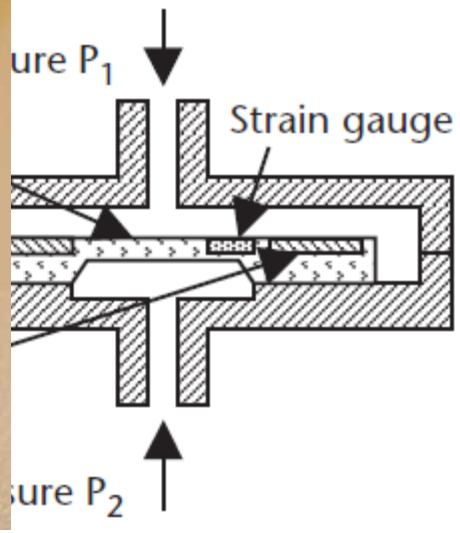
$$\gamma = \frac{p}{h} = \frac{7.85kPa}{1.35m} \times \frac{N/m^2}{9.8N/m^3} kg/m^3 = 0.59Mg/m^3$$

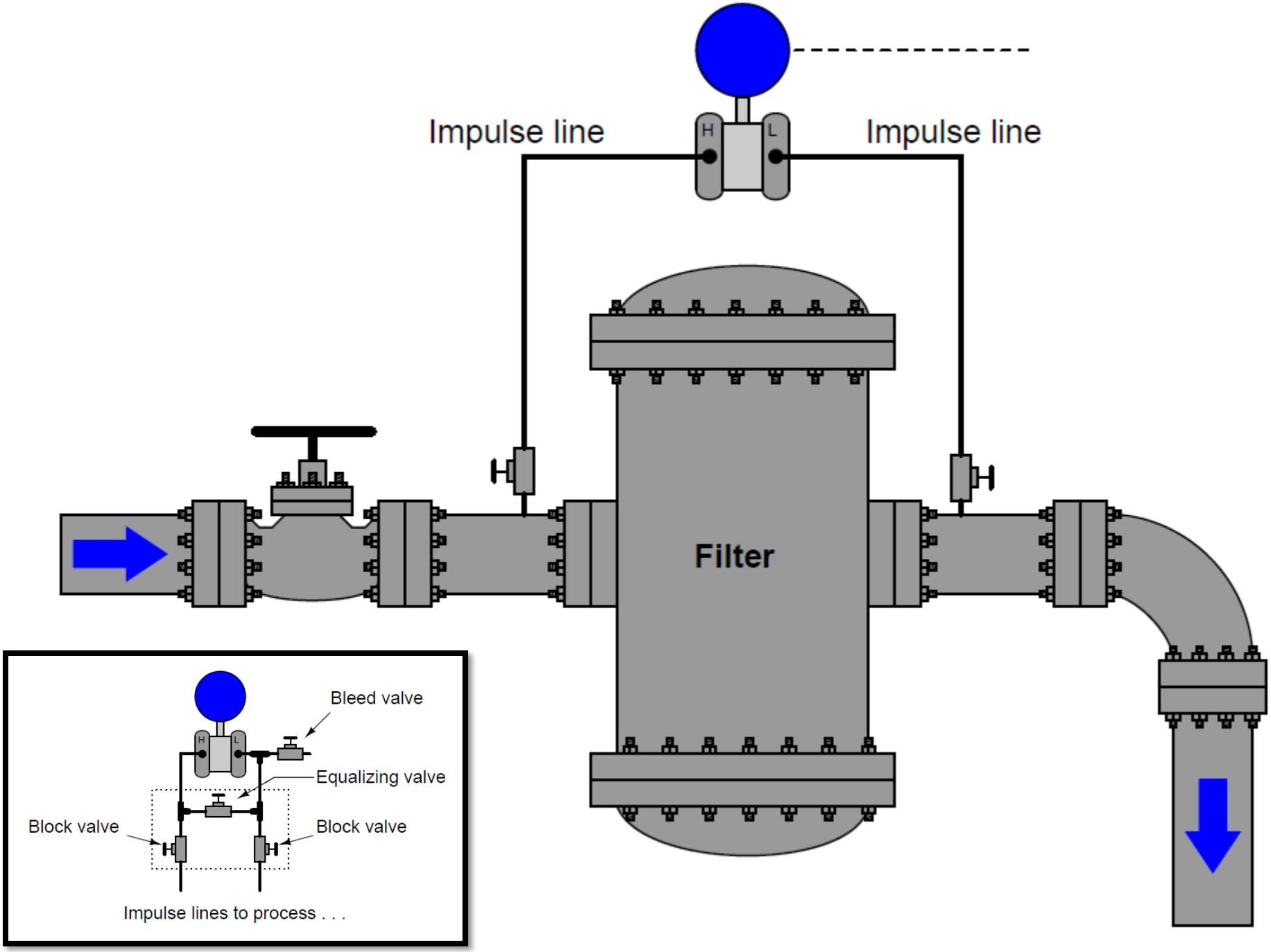
Pressure Gauges

Diaphragms, Capsules, and Bellows

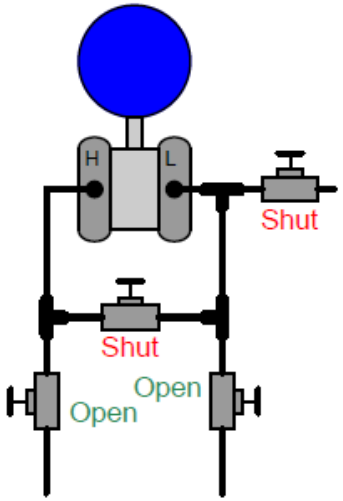
- Diaphragms cor al supported on a rigid frame.
- Pressure can be e sensing, with the other inlet port
- Pressures can b ifferential sensing, and absolute pr g a partial vacuum on one side of t






Impulse line
H
L
Impulse line
Filter
Bleed valve
Equalizing valve
Block valve
Block valve
Impulse lines to process . . .

Normal operation



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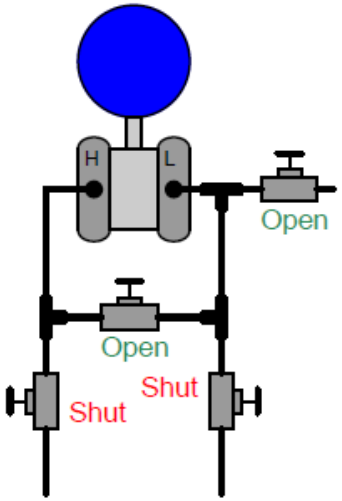
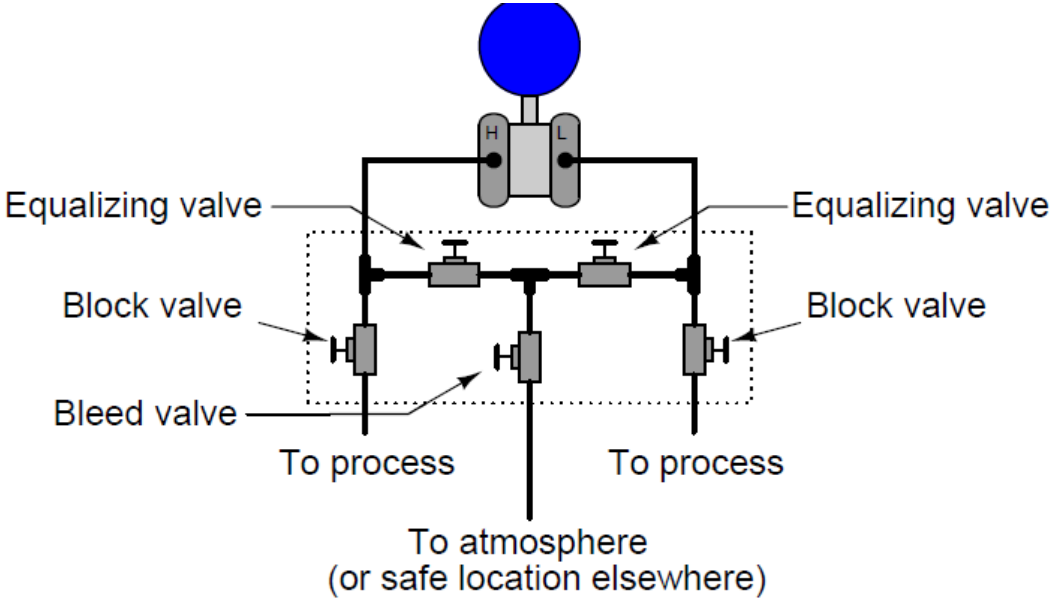
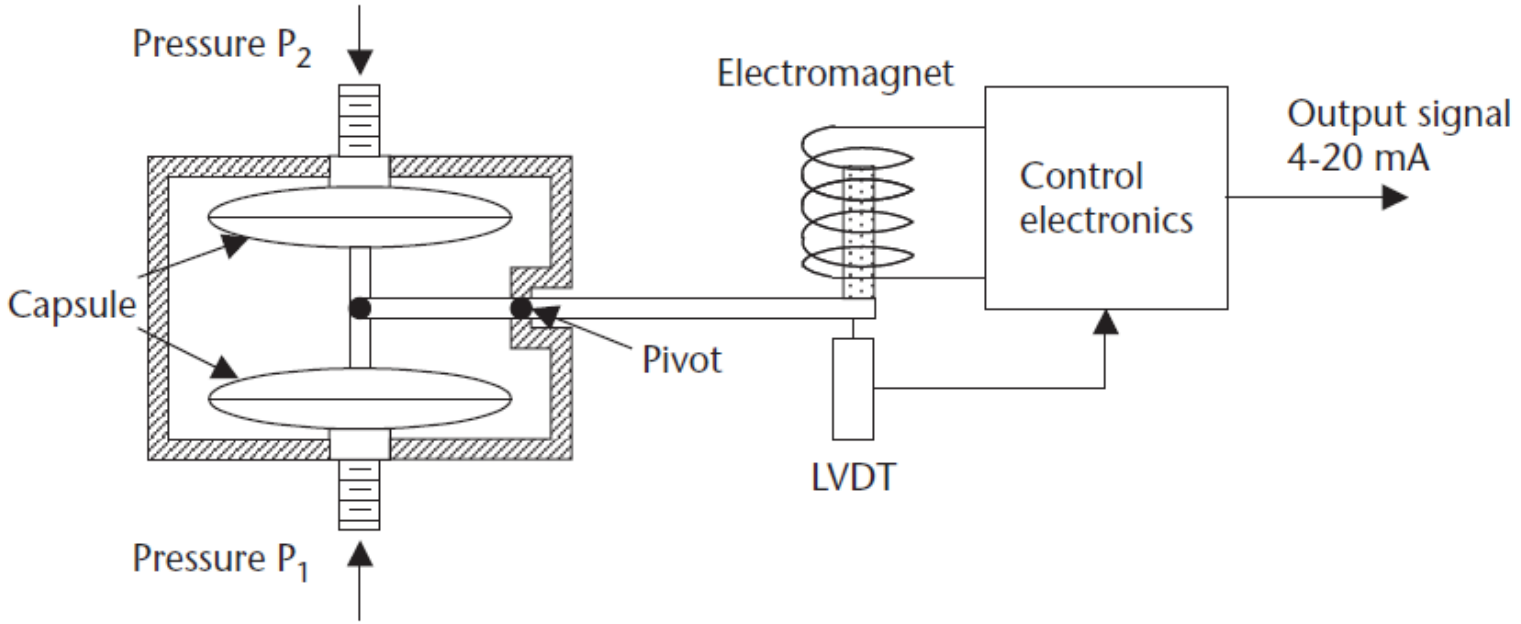




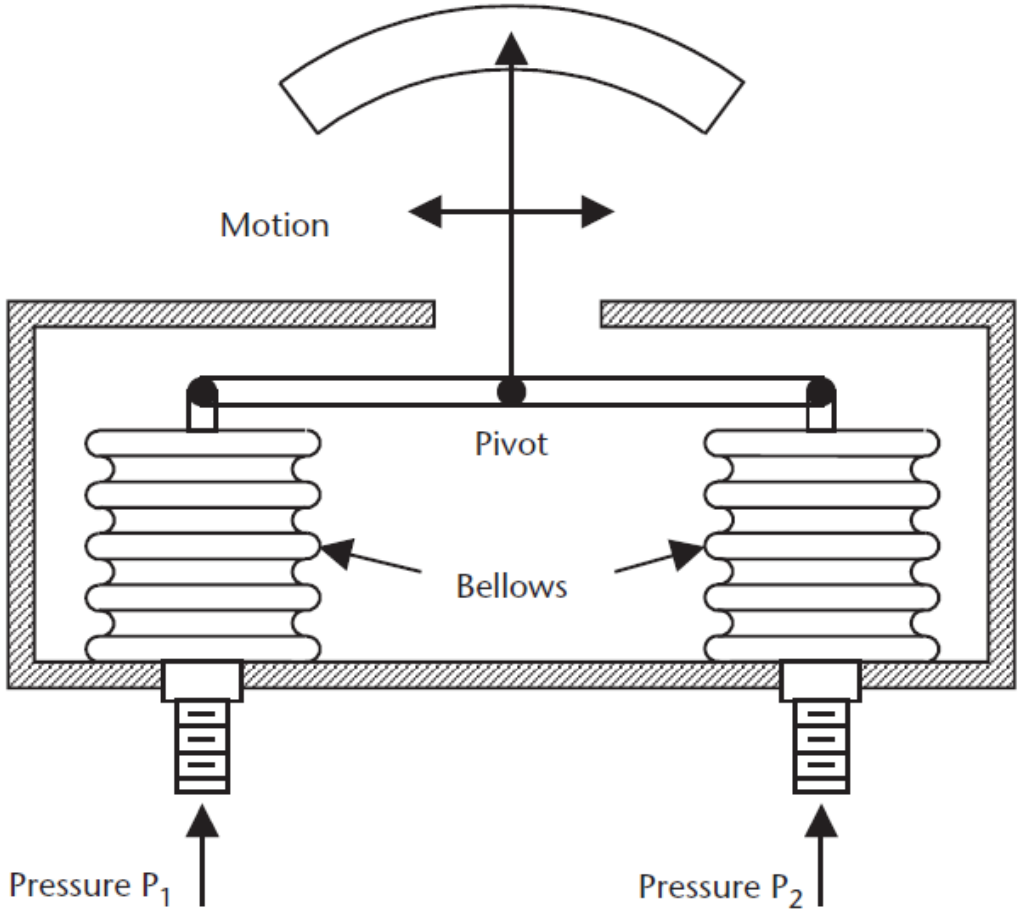
Capsules

- *Capsules are two diaphragms joined back to back.*
- *Pressure can be applied to* the space between the diaphragms, forcing them apart to measure gauge pressure.
- The pressure range of instruments using these materials is up to 50 psi (350 kPa).
- Capsules can be joined together to increase sensitivity and mechanical movement



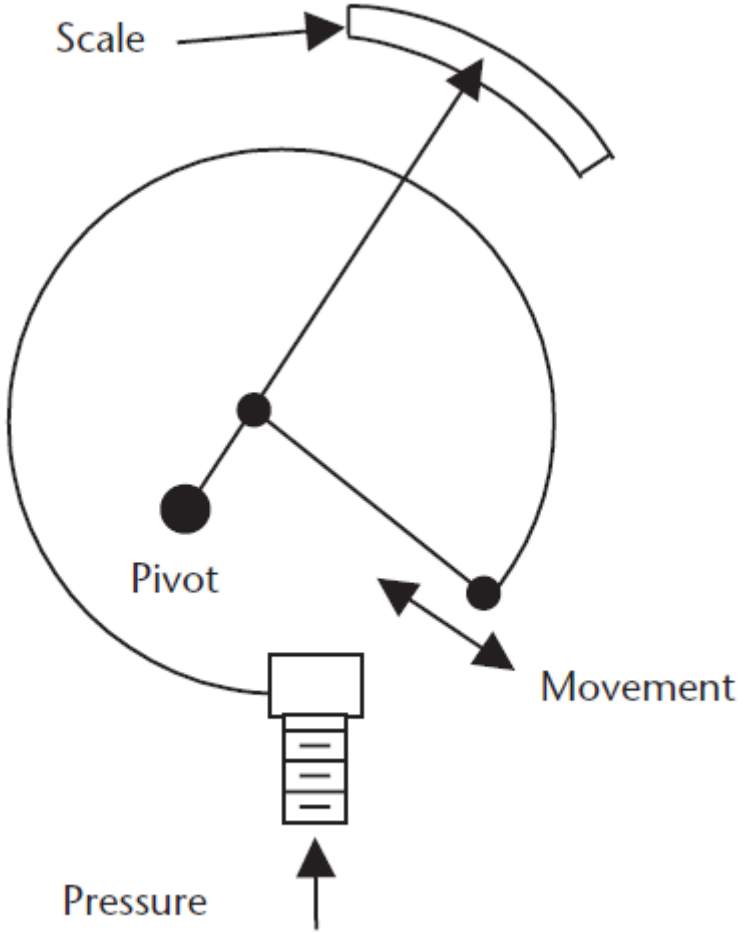
Bellows

- Bellows are similar to capsules, except that instead of being joined directly together, the diaphragms are separated by a corrugated tube or a tube with convolutions
- The bellows is the most sensitive of the mechanical devices for low-pressure measurements (i.e., 0.5 to 210 kPa)



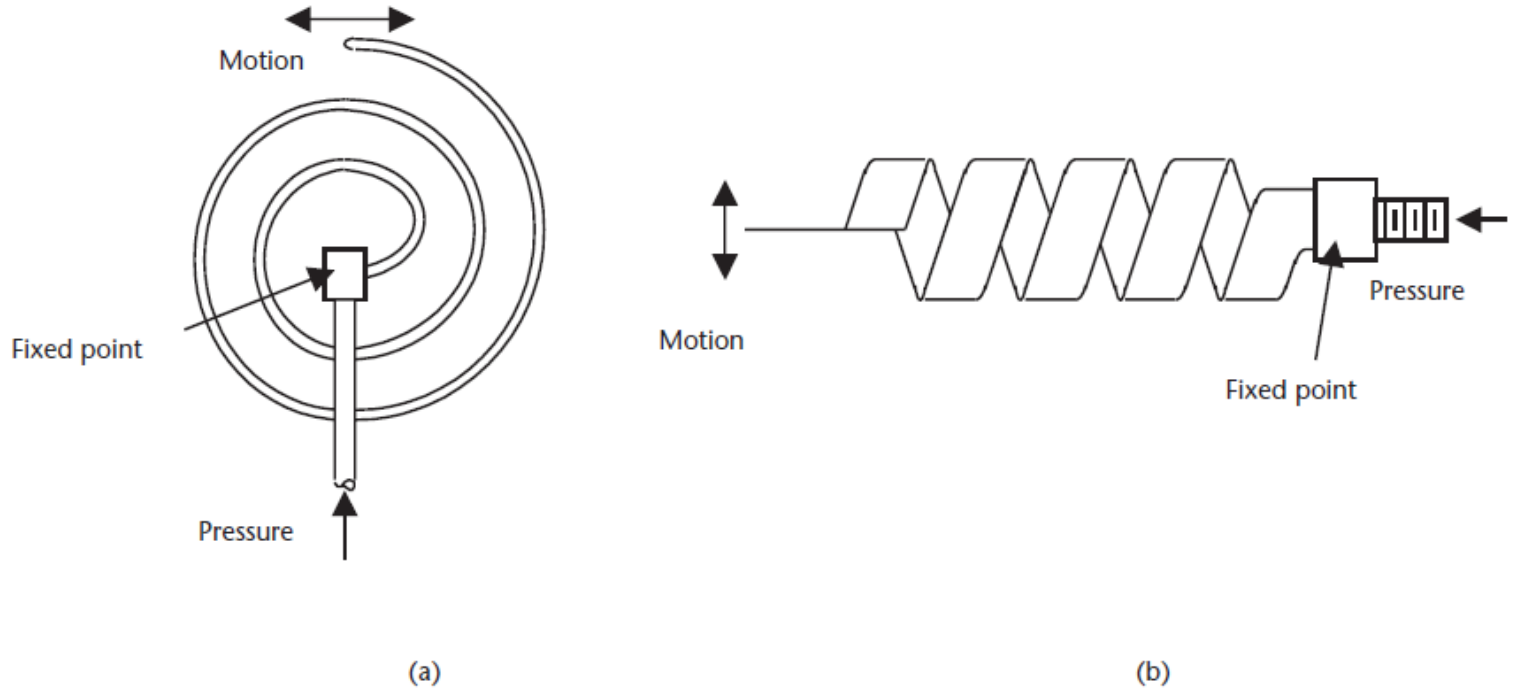
Differential bellows pressure gauges ($P_1 - P_2$) for direct scale reading.

Bourdon Tubes



Bourdon Tubes: Helical & Spiral Shape

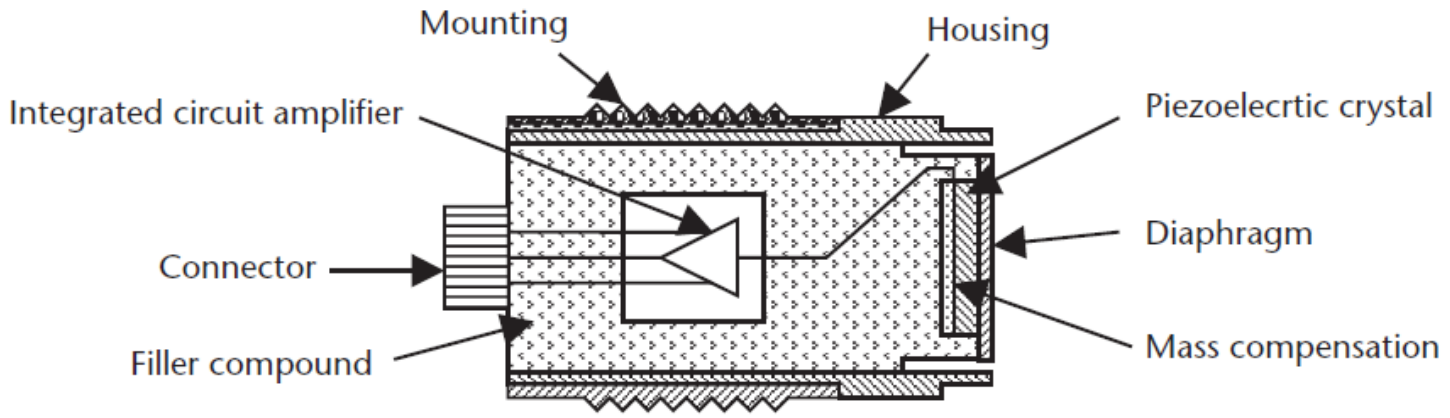
- Bourdon tubes can have a pressure range of up to 10,000 psi (70 MPa)



gure 7.9 Bourdon tube pressure gauges: (a) spiral tube, and (b) helical tube.

Other Pressure Sensors

- Barometers are used for measuring atmospheric pressure. A simple barometer was the mercury in glass barometer, which is now little used due to its fragility and the toxicity of the mercury.
- Piezoelectric crystals produce a voltage between their opposite faces when a force or pressure is applied to the crystal.



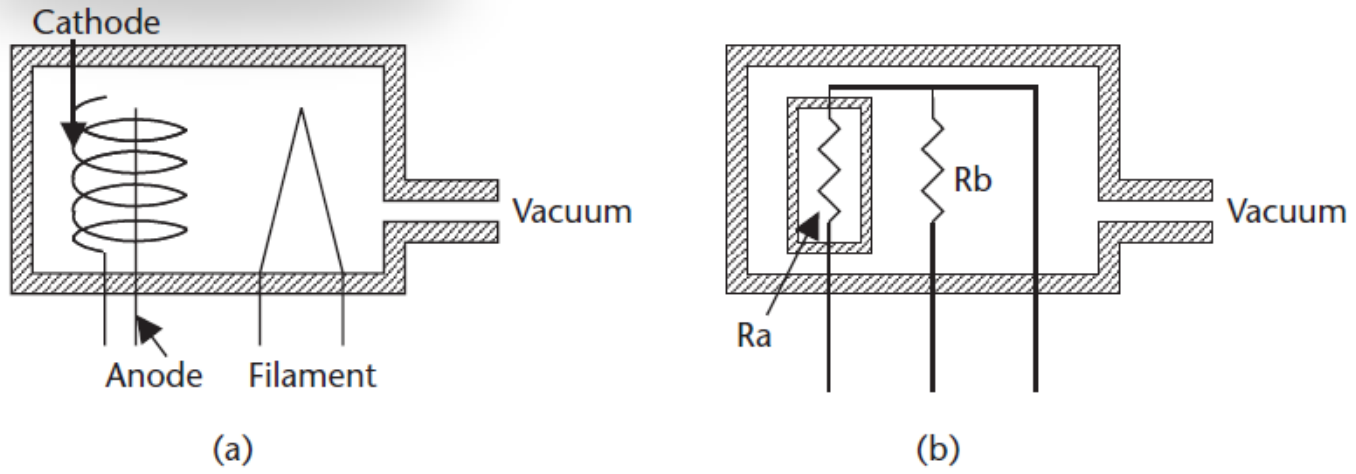
ıre 7.10 Cross section of a piezoelectric sensing element.

Vacuum Instruments

- Vacuum instruments are used to measure pressures less than atmospheric pressure.
- Bourdon tubes, diaphragms, and bellows can be used as vacuum gauges, but they measure negative pressures with respect to atmospheric pressure.
- The silicon absolute pressure gauge has a built-in low-pressure reference, so it is calibrated to measure absolute pressures

Ionization gauge & Pirani gauge

- Ionization gauges can be used to measure p to approxima The gas is ionized w he curren n two electrod is pro ns per unit vol to the
- Wit ouples, the P ms down $^{-3}$ atm). These on of heat ation from a heati gas molecules per unit volume in the low-pressu he pressure



7.11 Vacuum pressure gauges: (a) Ionization pressure gauge, and (b) Pirani gauge.

Approximate Pressure Ranges for Pressure Sensing Devices

Device	*Pressure Range, psi (MPa)*	*Temperature Range*	*Accuracy ±*
U-tube manometer	0.1–120 (0.7 kPa–1 MPa)	ambient	0.02 in
Diaphragm	0.5–400 (3.5 kPa–0.28 MPa)	90°C maximum	0.1% FSD
Solid state diaphragm	0.2–200 (1.4 kPa–0.14 MPa)	−50° to +120°C	1.0% FSD
Stainless steel diaphragm	20–10,000 (140 kPa–70 MPa)	−50° to +120°C	1.0% FSD
Capsule	0.5–50 (3.5 kPa–0.031 MPa)	90°C maximum	0.1% FSD
Bellows	0.1–800 (0.7 kPa–0.5 MPa)	90°C maximum	0.1% FSD
Bourdon tube	0.5–10,000 (3.5 kPa–70 MPa)	90°C maximum	0.1% FSD
Spiral Bourdon	0.01–4,000 (70 Pa–25 MPa)	90°C maximum	0.1% FSD
Helical Bourdon	0.02–8,000 (140 Pa–50 MPa)	90°C maximum	0.1% FSD
Piezoelectric stainless steel	20–10,000 (140 kPa–70 MPa)	−270° to +200°C	1.0% FSD